

INHERENTLY OFFENSIVE: AIRPOWER AND THE DIALECTIC WITH DEFENSE

BY

RYAN THULIN

A THESIS PRESENTED TO THE FACULTY OF
THE SCHOOL OF ADVANCED AIR AND SPACE STUDIES
FOR COMPLETION OF GRADUATION REQUIREMENTS

SCHOOL OF ADVANCED AIR AND SPACE STUDIES

AIR UNIVERSITY

MAXWELL AIR FORCE BASE, ALABAMA

JUNE 2017

APPROVAL

The undersigned certify that this thesis meets master's-level standards of research, argumentation, and expression.

STEPHEN D. CHIABOTTI, PhD (Date)

JAMES D. KIRAS, PhD (Date)



DISCLAIMER

The conclusions and opinions expressed in this document are those of the author. They do not reflect the official position of the US Government, Department of Defense, the United States Air Force, or Air University.



ABOUT THE AUTHOR

Major Ryan Thulin is a 2004 graduate of the USAF Academy, where he majored in mathematical science. His 13-year career on active duty with the Air Force has taken him to a variety of assignments and places, culminating with his last post as an F-35A Operational Test and Evaluation pilot at Nellis Air Force base.



ACKNOWLEDGMENTS

I would like to acknowledge several people without whose support I would never have completed this study. I want to thank Dr. Stephen Chiabotti, professor and Director of Doctoral Programs at the School of Advanced Air and Space Studies, for his guidance in completing this project. His patience was first-rate during the drafting of this report. I would like to thank Dr. James Kiras for his support in reviewing the draft of this document and providing comments to keep me on track.

Most importantly, I want to express my sincere appreciation to my wife for her love, patience, and understanding during those times when I was absent in spirit, off struggling with this paper. Her presence was very important to me and made all the difference in ensuring my success in completing this work.



ABSTRACT

This thesis contains an analysis of the technologies throughout history that challenge the offensive utility of the air weapon. The author examines a sampling of technologies from World War II through Korea such as radar, electronic attack, flak, and Window. Next, the author assesses surface-to-air missiles, radar-homing-and-warning systems, anti-radiation missiles, integrated air defense systems, stealth, and precision weapons to determine their effects on the offensive prowess of airpower. Next, the work surveys technologies from the present day and near future such as modern stealth, advanced surface-to-air missiles, advanced electronic attack, decoys, and swarm technology. The analysis illuminates the conclusion that airpower maintains its inherently offensive nature when confronted with increasingly capable defensive systems by combining multiple offensive technologies that possess complimentary effects. By examining how technology changes the offense-defense balance through the use of technologies the thesis also concludes that the theories posited by Giulio Douhet, who says the air weapon reigns supreme as an offensive tool, ring just as true today as they did in 1918. The final section of the work warns against over-generalizations that declare technologies irrelevant when faced with emerging defensive technologies. The combined effects of small offensive innovations enable airpower to maintain its offensive utility.



CONTENTS

Chapter	Page
DISCLAIMER.....	iii
ABOUT THE AUTHOR.....	iv
ACKNOWLEDGMENTS.....	v
ABSTRACT.....	vi
1 INTRODUCTION.....	1
2 WORLD WAR II THROUGH KOREA.....	8
3 VIETNAM WAR THROUGH OPERATION DESERT STORM.....	21
4 PRESENT DAY.....	33
5 TYING TOGETHER THEORY, HISTORY, THE PRESENT, AND THE FUTURE OF OFFENSE/DEFENSE IN AIR WARFARE.....	45
BIBLIOGRAPHY.....	53
Illustrations	
Figure 1 Cost Curve.....	43

Chapter 1

Introduction

A hundred, a thousand, ten thousand aerial means employed offensively are more profitable than fifty, five hundred, five thousand employed defensively and the same number offensively.

Giulio Douhet

Statement of the Research Question

States attempt to degrade the offensive advantages inherent in the air weapon primarily using technology. New technology is attractive in that it promises to enable a shift in the balance towards the defensive. History shows that the pace of these technological innovations is unlikely to slow in the future. Because the United States utilizes air power in nearly all of its military operations, countries will seek methods to limit the inherent advantages of the air weapon. This means that state and non-state actors will continue to develop technologies that provide asymmetric advantages against the overwhelming capabilities that air power provides. Can air power maintain its inherently offensive nature when facing increasingly lethal defensive technological advancements?

Background and Significance of the Problem

In order to understand the background and significance of the problem posed by this thesis one must examine the theory behind the inherently offensive nature of airpower. Carl Von Clausewitz maintains that the defensive is the stronger form of war. He explains, “defensive has a passive purpose: *preservation*; and attack a positive one: *conquest*. The latter increases one’s own capacity to wage war; the former does not. So in order to state the relationship precisely, we must say that *the defensive form of warfare is intrinsically stronger than the offensive.*”¹ The advent of the airplane challenges Clausewitz’s notion that the defense is the superior form of warfare. As Clausewitz makes the case for the defense, he argues, “any omission of attack—whether from bad

¹ Carl von Clausewitz, Michael Eliot Howard, and Peter Paret, *On War*, First paperback printing (Princeton, NJ: Princeton University Press, 1989, 358.

judgment, fear, or indolence-accrues to the defender's benefit."² This maxim does not apply when considering the air weapon. To be effective, the defender using airplanes must maintain significant combat power either airborne or at a high state of ground alert. It can be argued that this type of readiness is unsustainable over a long conflict. The offender is able to choose the time place for the attack, massing his forces to overwhelm the defender. For this very reason, aside from a few notable exceptions such as the Battle of Britain, very few air defenses have been successful throughout history when facing massed air attack. Clausewitz's theories on the defensive continue to break down when one discovers that interior and exterior lines do not necessarily apply when viewed from the airman's perspective. Clausewitz states "the one advantage the attacker possesses is that he is free to strike at any point along the whole line of defense, and in full force: the defender, on the other hand, is able to surprise his opponent constantly throughout the engagement by the strength and direction of his counterattacks."³ As we will see through the theories of Giulio Douhet, the notion that Clausewitz posits here is exceedingly difficult using the air weapon. Following Clausewitz's defensive theory, a majority of a state's combat air power would be employed defending the country's vital centers against air attack. This dispersal of air assets reduces their effectiveness and ability to mass for counterattacks. The ability to counterattack is a key component to Clausewitz's theories favoring the defensive. The effectiveness of counterattacks from interior lines breaks down when employing airpower.

Although Clausewitz's theory of war does not apply in many areas where airpower is concerned, he did realize the potential paradigm-shifting nature that technology often plays. Thomas Kuhn defines a paradigm as sharing two essential characteristics, "their achievement was sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity. Simultaneously, it was sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve."⁴ Clausewitz states, "if the offensive were to invent some major

² Carl von Clausewitz, *On War*, 357.

³ Carl von Clausewitz, *On War*, 360.

⁴ Kuhn, Thomas S. *The Structure of Scientific Revolutions*. fourth ed. Chicago: The University of Chicago Press, 2012, 11.

new expedient—which is unlikely in view of the simplicity and inherent necessity that marks everything today—the defensive will also have to change its methods. But it will always be certain of having the benefit of terrain, and this will generally ensure its natural superiority; for today the peculiarities of the topography and the ground have a greater effect on military action than ever.”⁵ Clausewitz acknowledges that a major technological advantage is required to change the nature of warfare. The airplane is the paradigm-shifting expedient that Clausewitz refers to, as the topography becomes nearly irrelevant to flight operations. Another key point in this portion of Clausewitz’s theory is his acknowledgement that the defense will have to change methods in the face of major new expedients. This thesis attempts to examine changing methods, in the form of technology, to determine if airpower maintains the paradigm-shifting effects to which Clausewitz alludes. In other words, does the offensive nature of airpower attract an enduring group of adherents and is it sufficiently open-ended to leave problems for the current practitioners to solve?

In spite of the defense being the stronger form of warfare, Clausewitz acknowledges the pitfalls of dispersing one’s forces to defend multiple objectives, a point that our next theorist emphasizes. Clausewitz addresses the dangers of such a strategy when he states, “if the defender were compelled to spread his forces over several points of access, the attacker would obviously reap the advantage of being able to throw his full strength against any one of them.”⁶ Clausewitz argues that the defensive is the superior form of warfare but also acknowledges some of the concepts that prove airpower is an inherently offensive weapon.

Unlike Clausewitz, Giulio Douhet had the advantage of witnessing the airplane in action before penning his theory on warfare. Douhet argues that, because of the airplane, the offensive is the superior form of warfare. Douhet posits, “because of its independence of surface limitations and its superior speed—superior to any other known means of transportation—the airplane is the offensive weapon par excellence.”⁷ Douhet

⁵ Carl von Clausewitz, *On War*, 362.

⁶ Carl von Clausewitz, *On War*, 364.

⁷ Giulio Douhet, *The Command of the Air*, USAF Warrior Studies, Washington, D.C: Office of Air Force History, 1983, 15.

was able to see that the air weapon made the topography of the battlefield irrelevant. The airplane's ability to surmount nearly any defensive architecture, including terrain, helps to prove it is inherently offensive in nature. Douhet continues his argument by highlighting how ineffective aerial defenses are. Douhet uses an example in which he assumes that a notional country has twenty objectives to defend with its air forces. He argues, "so that to defend ourselves we would need a minimum aerial force twenty times as large as the attacking force of the enemy—a solution of the problem which partakes of the absurd because the airplane is not adaptable to defense, being pre-eminently an offensive weapon."⁸ Even during World War II, when both the Axis and Allies maximized production of aircraft, they were unable to mount the type of defense that Douhet alludes to. There are far too many critical targets and far too few airplanes to make the defense work. Air forces required supporting technology, such as Radio Detection and Ranging (radar), to mount effective defenses. Today, airplanes are more technologically advanced and take much longer to produce than in World War II. This reality reinforces Douhet's argument that the airplane is ineffective as a defensive tool.

To further highlight the difficulty inherent in an aerial defense Douhet poses a hypothetical conflict between two states. "If two nations, A and B, have equal aerial resources, and A uses *all* of them offensively while B uses *all* of them defensively, B automatically and gratuitously ensures A against any aerial offensive but does not ensure itself against an offensive from A. Consequently, B plays into the hands of A, and does not defend itself either."⁹ All of this together buttresses the fact that the air weapon is indeed offensive in nature. Although airplanes are sometimes able to mount effective defenses, as evidenced in the Battle of Britain, they are much better suited to offensive operations.

Douhet continues by shifting his argument to the benefits of the offensive employment of airpower. He states "it is much easier for others to attack us than for us to attack them. For this reason a neutralization of aerial offensives would work to our advantage and not to theirs; for then, having done away with the aerial field, we should

⁸ Douhet, *The Command of the Air*, 17.

⁹ Douhet, *The Command of the Air*, 241.

fight, as in olden times, only on land and sea.”¹⁰ What Douhet is saying here, rather cryptically, is that one of the primary aims of the air weapon is to go on the offensive against the enemy airfields. In other words, the only way to effectively defend against an enemy air force is to take the offensive and destroy it while it is on the ground. Once the enemy air weapon is defeated, the belligerents can then fight the war following the tried-and-true Clausewitzian methods. Douhet is arguing that, although the airplane is a ground-breaking technology, it does not drastically alter the nature of warfare itself. The Clausewitzian model still applies but the enemy air forces must be defeated before attempting to apply the traditional theories. Douhet states “the most practical and realistic way of preventing enemy planes from coming over and bombing us is to destroy them, just as the most practical and realistic way of preventing land and sea offensives against our country is to destroy the enemy’s land and sea forces.”¹¹ Douhet contends that the air weapon is inherently offensive but does this fact hold true in the face of increasingly effective defensive technologies?

Limitations of the Study

Despite the fact this research was carefully prepared, there are limitations and shortcomings inherent in a study of this nature. For two reasons, most of the sources of information in the study are secondary in nature. The first reason is the quality of the secondary sources used to examine technologies through the Gulf War made primary sources unnecessary. The second reason involves access. The sensitive nature of the modern technology involved in the research makes access to primary sources difficult. Overcoming this limitation, while maintaining the integrity of the outcomes, proved to be relatively simple. The research focuses on concepts and theory rather than the details of specific technologies. This limitation points to the need for additional research as primary sources on modern technologies become available. Bias is an additional limitation of this study. The author is an active duty Air Force officer with a fifth-generation fighter background. This bias is difficult to overcome, but review by two independent professors helps to reduce the impacts on the conclusions. The research

¹⁰ Douhet, *The Command of the Air*, 239.

¹¹ Douhet, *The Command of the Air*, 241.

methodology that focuses on concrete historical examples also works to reduce the bias in the findings of this study. Examining specific technologies within their historical context also helps to reduce the inherent bias generated from the author's background.

Definitions and Assumptions

In lieu of a list containing unambiguous definitions, this document presents relevant definitions within the text of the study to aid in the clarity of the argument. However, this study often references the offense-defense balance, a concept that warrants a detailed definition up front. Ted Hopf, writing in *The American Political Science Review*, argues, "the offense-defense balance consists of three elements. The first is the technical offense-defense military balance concerning the relative military advantages enjoyed by the offense or defense on the battlefield, that is, castles versus cannons, machine guns versus trenches, and so on. The second element is the cumulativeness of power resources, or the relative availability of the resources that underlay military capability and the relative ease of their extraction by occupying states. The third element is the set of strategic beliefs held by leaders of the great powers, their relative concern for their reputation, or credibility."¹² The present study focuses on the first of Hopf's three elements, the technical military balance. The study is scoped to examine the balance between measure and counter-measure with respect to the air weapon.

This thesis assumes the reader possesses basic knowledge of general military theory as well as basic air power theory. A rudimentary knowledge of principles relating to the electromagnetic spectrum, low-observable aircraft, surface-to-air missile technology, and radar theory will also benefit the reader.

Preview of the Argument

Chapter two examines technological advancements from World War II through Korea. The research begins by examining how radar technology enabled the defense of England during the Battle of Britain. The work then examines the Axis reaction and slow adoption of radar technology. The thesis seeks to show that Germany's slow adoption of radar technology contributed to air power's ability to maintain overwhelming offensive

¹² Hopf, Ted. "Polarity, The Offense Defense Balance, and War." *The American Political Science Review* 85, no. 2, 1991, 476.

power over occupied Europe. The research next looks at the peculiar effects of early advances in the field of electronic attack. The technology proves to limit and enhance air power's offensive capabilities depending upon the strategy that underpins its use. If the offensive advantage of airpower was degraded by radar and electronic attack, did Window restore air power's offensive prowess? Next, the work takes a detailed look at the significant German investment in anti-aircraft artillery. If flak technology proves to degrade the effectiveness of offensive operations, what strategies did leaders use to minimize its effects? The chapter concludes with a brief look at the lack of technological development during the Korean War and its effects on the offensive utility of airpower.

Chapter three examines technologies introduced from the Vietnam War through Operation Desert Storm. It begins with an examination of surface-to-air-guided missiles, specifically the SA-2, in North Vietnam. The research attempts to determine if the introduction of the SA-2 into the Vietnam conflict limited the offensive utility of airpower. The study then examines radar-homing-and-warning systems, installed on U.S. fighter-bombers, and their effects on offensive warfare over Vietnam when facing a radar-guided surface-to-air-missile threat. The chapter examines anti-radiation missiles and how they attempted to re-establish air power as a decisive offensive tool against North Vietnamese missile forces. Next, the work asks whether Iraqi attempts at establishing an integrated air defense system mitigated the offensive advantages developed during the conflict in Vietnam. If the Iraqis' air defense systems did indeed degrade the offensive utility of airpower, did early stealth technology inherent in the F-117 re-establish the airplane as a decisive tool? Finally, the chapter concludes with an examination of precision weapons and their effects on air power's offensive nature.

Chapter four surveys technologies from the present day. The chapter begins by defining the difference between modern stealth and the principles used by the legacy F-117. Next, the chapter seeks to determine the effects of modern stealth on airpower's effectiveness. Next, the thesis examines the counter to modern stealth, the advanced surface-to-air missile. Does the range and capability possessed by modern advanced surface-to-air missiles render stealth and therefore airpower irrelevant? If so, do decoys and swarm technologies serve to restore airpower's utility. Chapter five concludes the thesis with the principle findings, conclusions, and implications of the study.



Chapter 2

World War II and Korea

In the battle for control of the skies over Europe, technology played a critical role in shifting the balance between the defenders and the attackers during the course of the war.

Edward B. Westermann

Modern air-defense thinking, with the interplay of technology and suppression techniques, started during the great-power conflict of World War II and continued through the Korean War. Technology advanced at an exceedingly rapid rate due to the vast resources available for wartime research and development during World War II. The advancements in technology set the stage for continuous shifts in the offense-defense balance with respect to air defenses, suppression of air defenses, and air-defense countermeasures. The shifts in the offense-defense balance caused military leaders to change force structures and allocation of resources as thinking about suppression of enemy air defenses changed. By examining early technological advancements in air defense and how they affect both the offense-defense balance and strategic thinking, one can begin to build insight into future technologies and how they may shift the balance. Advancements in radar technology employed during the Battle of Britain significantly contributed to the defeat of the Luftwaffe over the English Channel. Radar use during the Battle of Britain and the lack of a German response to the technology show the effectiveness of defensive technology when left unsuppressed. Radar continued to be an effective tool for shifting the offense-defense balance toward the defense throughout the Korean War as it contributed to United Nations air superiority over the Korean peninsula. Early efforts at electronic attack during World War II show how some technologies can shift the offense-defense balance in either direction. The strategy behind an electronic-attack campaign proves to be critical in how the offense-defense balance shifts in response. Anti-aircraft artillery and the technological advancements that enhanced the weapon proved to be the most significant air-defense development that bolstered the defense during World War II and the Korean War. The technology accounted for significant allied losses during offensive bombing campaigns in continental Europe

causing a response that highlights a significant obstacle to the offensive utility of airpower.

Technological advances brought about during the great-power conflict of World War II provide numerous examples of technology radically shifting the offense-defense balance with respect to both air-defense technologies and efforts to counter such equipment. The shifts in the offense-defense balance and the military responses to the shifts provide a window into strategic thinkers' minds with respect to air defenses. As an answer to enemy radar systems, the Allied development of Window chaff systems shifted the balance back toward the offense. Electronic means prove to be an anomaly as the technology serves to shift the offense-defense balance depending on the strategic goals underpinning the campaign. Although electronic attack is an anomaly, its use in World War II enlightens strategic thinkers' decisions in response to changes in the air-defense environment.

Radar

The Battle of Britain saw the first effective operational use of radar during a strategic air battle. The British built an extremely effective command-and-control network around innovative early-warning radar sites throughout the English countryside.¹ The result was unprecedented levels of information on German air raids from the time of departure all the way through their intended targets. English radar operators worked to confirm that returns on their early-warning radar screens were indeed enemy aircraft through intense training, correlation with other radar sites, and a visual-observer network along the English coast. The presence of a group of enemy aircraft would then be sent up a sophisticated network of landline telephones to higher echelons of command and control. The radar sites would continually track the speed, direction, altitude, and strength of each group of enemy aircraft. Military leadership at command-and-control centers would then direct interceptor bases to launch fighter aircraft. Anti-aircraft artillery, acoustic tracking devices, and searchlight units would use the data from the radar sites, funneled by command-and-control networks, to direct resources towards the

¹ Bungay, Stephen. *The most dangerous enemy: a history of the Battle of Britain*. Aurum Press Limited, 2010, 69.

incoming enemy forces.² Radar was the key to the British early-warning system that enabled an optimized air defense.

The Germans were slow to recognize the shift toward the defense that the British early-warning radar network afforded. Stephen Bungay supports this when he argues, “what none of them [Germans] understood was the nature of the radio-based fighter control system linked in to the British detection network.”³ Because of their slow recognition, the Germans failed to initiate any significant suppression campaign against the English defenses. Aside from a few relatively ineffective Luftwaffe attacks on English radar sites, the British enjoyed an uninterrupted flow of information during the Battle of Britain and beyond. The dramatic shift in the offense-defense balance afforded the British valuable time while German aircraft made the long journey across the English Channel. The radar sites also gave information about intended German targets, further improving British responses to the raids. The accurate information provided by the radar sites allowed for British fighters to be held on the ground in an alert status, versus being airborne at all times in anticipation of raids. The radar provided the time delay needed to hold fighters on the ground and launch only in response to specific German raids. British leaders quickly realized that the offense-defense balance had shifted in their favor. By capitalizing on their realization, they saved considerable resources. The shift towards the defense provided by radar also allowed the British to effectively mass their forces against specific German attacks. Without the radar information very few aircraft would be available at any one time due to the strain caused by flying around the clock in anticipation of hostile raids. With the fighters on ground alert, the British could wait and then mass at the critical point to exert decisive effects on German air raids.

The British and their allies were quick to perceive the shift towards the defense that radar had created. England and the United States witnessed the effects of an inadequate suppression campaign against a well-designed air defense network. The Allies translated the lessons-learned during the Battle of Britain into an effective suppression campaign during the Normandy invasions in June of 1944. The Allies saw how difficult the German offensive operations were in the face of an effective air defense

² Bungay, *The Most Dangerous Enemy*, 63.

³ Bungay, *The Most Dangerous Enemy*, 69.

network. Because of these lessons, Allied commanders realized how difficult the Normandy landings could be if German air defenses were optimized with radar. The Allies responded to the threat with a well-composed suppression strategy concentrated on the German early-warning radar network. The British started the effort by locating all of the German radar antennas. Ronald Clark explains, “all the 120 sets grouped in forty-seven stations were by this time known to Air Ministry Intelligence.”⁴ With all of the German early-warning-radar locations known to the Allies, the next step logically was to strike each of the sites. The rationale used here by the commanders of the time was one of the first instances of strategic thinking about Suppression of Enemy Air Defenses (SEAD) that is still in practice today--the concept of graduated risk based on the strategic situation embodied by three words: avoid, suppress, and/or, destroy. The Allies were unable to avoid detection by the German early warning radars because of the German Freya early warning radar’s long-range detection capabilities.⁵ The next step in the graduated-risk methodology was to explore the possibility of suppressing the radars. Electronic attack was the only means available to the Allies for suppression and will be discussed later in this chapter.

The Allies assumed that suppression alone would not cover the invasion fleet crossing the channel, so they arrived at the final stage of the graduated-risk game plan: the radar sites must be destroyed. Reginald Victor Jones explains, “but if we could make direct attacks on German radar stations, some of them could be eliminated, and the operators in the others might be so disturbed as to observe less accurately in the presence of jamming and Window.”⁶ The Allies took full advantage of the intelligence on the location of the German radars and were willing to accept the risk involved in direct attacks on the antennas with fighter-bomber aircraft. The risks involved with the suppression campaign and the forethought of the commanders ultimately paid off. Clark

⁴ Clark, Ronald William. *The Rise of the Boffins*. Phoenix House, 1962, 229.

⁵ The German Freya radar provided early warning of impending aircraft raids on occupied Europe. The radars had a range of 160 kilometers (~86 NM). With 120 sets of Freya radars on the occupied coast, it would have been nearly impossible to simply avoid detection especially considering the large number of aircraft involved in a typical allied bombing raid.

⁶ Jones, Reginald Victor. *Most Secret War*. Penguin UK, 2009, 400.

posits, “by the night before D-day only one in six was still working properly.”⁷ The Allies were able to damage or destroy nearly all of the German radar sites, effectively blinding the Wehrmacht to the approaching invasion fleet.

From the earliest use of the technology, radar shifted the offense-defense balance in favor of the defense. German commanders witnessed this phenomenon as they lost the Battle of Britain to well-timed and massed airborne defenses over the English Channel. German commanders failed to recognize the shift to the defense that radar had caused, learning the lesson only as the Luftwaffe was eventually bled dry by English forces. Allied commanders, on the other hand, were quick to recognize the shift to the defensive that their radar technology caused. Allied senior commanders learned quickly that an enemy early-warning network, left intact, greatly hindered an attacker’s ability to gain and maintain air superiority. Allied commanders projected these important lessons on to the planning efforts of D-Day showing great forethought and wisdom. The Allied air forces contributed to the successful landings on D-Day by destroying nearly all of the German radar sites that would have provided advanced notice of the invasion fleet.

Electronic Attack

Electronic-attack technology shifts the offense-defense balance in both directions depending on how the technology is used within the context of the conflict. The strategy of employment matters. Electronic-attack technology first emerged as a military weapon during World War II. Strategic commanders on both sides quickly recognized the utility of the technology and its potential to shift the offense-defense balance. Two examples from World War II highlight how electronic attack shifted the balance. The Allies’ use of electronic attack to blind German early-warning radars to enable offensive actions highlights how electronic attack can shift the balance towards the offense. German jamming of allied radar-bombing signals shows electronic attack’s ability to shift the balance towards the defensive.

The use of electronic attack during the D-Day invasion provides a sound example of how the technology shifts the offense-defense balance towards the offense. As noted earlier, the Allies had all 120 German early-warning radar sets located well before the

⁷ Clark, Ronald William. *The Rise of the Boffins*. Phoenix House, 1962, 229.

Normandy landings and destroyed or disabled *nearly* all of the sites. A handful of the radar sites were intentionally left untargeted by the Allies to exploit electronic-attack technology. The Allies used electronic attack to raise the gain in the remaining Nazi radar antennas, not to a point where German defenses were completely blinded, but to mask a fake invasion fleet moving towards Calais. The remaining Nazi radar sites, manned by experienced operators, could see a few radar contacts through the jamming but could not decipher whether they were a fake invasion fleet or the actual landing craft. The ruse worked, the German command-and-control system was not advised of the true location of the landing until soldiers on the Normandy coast heard the sounds of troop carriers launching landing craft. Clark shows the importance of this effort when he states, “the jamming of the enemy’s radar, the provision of a unique navigation system, and the operation of a deception plan which successfully foiled the enemy into miscalculating where the blow would fall, were only the most important of the contributions which radio and radar made to pre-D-day preparations.”⁸ Electronic attack successfully tipped the balance towards the offense by playing a part in ensuring the successful landings on the Normandy beaches in 1944.

The Germans recognized the utility of electronic attack but employed it to shift the offense-defense balance toward the defense. They used electronic attack for defensive purposes in their attempts to jam British radar-bombing signals from the Gee radio-navigation equipment. The Gee system relied on ground and air-based radio equipment to enable bombers to navigate and employ weapons with varying degrees of accuracy through the weather. William Rankin notes, “they [the Germans] began jamming Gee transmissions over Germany soon after they discovered the system in August 1942.”⁹ The Allied Gee equipment continually radiated specific, unchanging, frequencies, making them exceedingly easy for the Germans to intercept and exploit. The Germans simply had to intercept the Gee frequency and re-transmit either spurious pulses on the same frequency or high-power noise to disable the system. The spurious pulses made it impossible for bombers equipped with Gee equipment to decipher the

⁸ Clark, *The Rise of the Boffins*, 230.

⁹ Rankin, William. "The Geography of Radionavigation and the Politics of Intangible Artifacts." *Technology and Culture* 55, no. 3, 2014, 622.

valid signals originating in England from the invalid signals emanating out of occupied territory. The technique rendered the navigational utility of the Gee system useless. Weather in the European theater often made visual bombing impossible, forcing crews to rely on radar-bombing techniques enabled by the Gee equipment. Effective electronic attack on the Gee system removed the British bombers' ability to accurately deliver their offensive ordnance. The Germans effectively shifted the balance towards the defense by using electronic attack.

The balance between offense and defense in electronic warfare during the early stages of World War II was highly dependent upon the strategy behind the use of the technology. Important strategic thinking emerged on the Allied side versus the Axis side regarding the emerging technology. The Allies used the technology to enable bombing operations and the Normandy landings, helping to shift the balance towards the offensive. The Germans used the technology on the defensive to thwart Allied bombing raids into occupied Europe. The technology served both offense and defense, often at the same time.

Flak

In response to Allied bombing raids into German occupied territory, the Wehrmacht began an aggressive campaign to build effective air defenses. As early as 1932 Germany started a program calling for development of advanced anti-aircraft artillery guns, range finders, shells with increased muzzle velocities, mechanically timed fuses, and searchlights. Along with existing technology, the Germans initiated research and development on exotic technologies such as infrared tracking devices, barrage rockets, and radio locators and listening devices.¹⁰ The foresight displayed by German strategic leaders shows that they envisioned an effective air-defense program concentrated around flak.

The German experience with flak dates back to World War I. Despite the excitement and attention surrounding the dogfights of the First World War, air-to-air combat accounted for a relatively small number of Allied aircraft losses. German flak

¹⁰ Westermann, Edward B. *Flak: German Anti-aircraft Defenses, 1914-1945*. University Press of Kansas, 2001, 47.

accounted for a far larger number of losses in the Great War. Edward B. Westermann notes, “in the first ten months of 1918 alone, German flak accounted for 47 percent of the total Allied aircraft losses.”¹¹ The Germans witnessed the effects of artillery and committed to flak defenses in future conflicts. Flak in World War I had significant technological limitations that the Germans needed to solve in order to create effective air defenses. Westermann explains, “the primary limitation of the guns remained, however, technological. The difficulty associated with tracking a target in three-dimensional space and coordinating the fire of the guns still proved a formidable challenge.”¹² To surmount these challenges significant forethought and investment would be required of the Wehrmacht.

During the interwar period, Germany started an aggressive program to build its air defenses based on lessons of the First World War. In 1932, Germany started its program to build air defense around flak. The goals of the program obviously included the ability to destroy as many enemy airplanes as possible but also contained more nuanced objectives that were easier to achieve. The Germans, as well as the Allies, observed flak’s ability to disrupt formations of attacking aircraft, thereby significantly reducing bombing accuracy. If bombers maneuvered to avoid flak, the formations would split up, reducing both mass and accuracy of the bombs on target. An account from a Royal Air Force bomber pilot during an attack on the port of Saint-Nazaire highlights this effect: “One feels like a sitting pigeon, so exposed or like a man walking across Piccadilly with no trousers on would feel.”¹³ The Americans experienced the same effects from flak. A May 1942 Bomber Command memo states, “the enemy has put up a very great deal of effort into his A.A. [anti-aircraft] defenses with the result that our bombers have to face fire of considerable intensity. Much evasive action is normally taken with a view to minimizing the effectiveness of this fire and bomb-aiming is in consequence rendered considerably less accurate and many bombs are wasted.”¹⁴ Anti-aircraft artillery also supports fighter operations. Westerman explains, “by damaging bombers or loosening

¹¹ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 27.

¹² Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 22.

¹³ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 106.

¹⁴ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 204.

the bomber formation, the flak was creating opportunities for the fighters to bring their attacks to bear.”¹⁵ Flak contributed to a number of the fighter victories during World War II.

An additional, more obvious, effect of flak was that it drove bombers to higher altitudes reducing bombing accuracy. Both sides, the Axis and the Allies, realized the defensive potential of this byproduct of flak. On the German side Dr. Heinrich Hunke, a military writer, “highlighted the important role played by flak in affecting the ‘morale’ of Allied pilots and forcing Allied aircraft to fly at higher altitudes, thus reducing bombing accuracy.”¹⁶ On the Allies’ side, the effects of flak were even more stark. Westerman highlights “at a conference in late March 1945, General [Carl Andrew] Spaatz, the commander of the U.S. Strategic Air Forces, remarked that flak was the ‘biggest factor’ affecting bombing accuracy.”¹⁷

Both sides realized the significant effects of flak. The Germans exploited the technology to great effect. Westerman explains, “flak defenses accounted for over half of the USAAF’s combat losses during the war in Europe, downing almost 5,400 aircraft compared with the 4,300 aircraft shot down by Luftwaffe fighters.”¹⁸ The Allies had little response to the flak other than bombing from higher altitudes and attempting to avoid known areas with dense flak defenses. The German attention to defense and the adjustments made prior to conflict illuminate the need to think through new technology, form a vision, and act upon it.

Allied SEAD Efforts Against Flak

The Allies attempted to suppress the German flak sites with limited success. Due to the vast numbers of anti-aircraft artillery pieces fielded by German forces, the suppression efforts normally achieved only localized success around key targets. For example, Bomber Command “in the three months following the Allied invasion...concentrated on providing tactical support to Allied ground forces in

¹⁵ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 89.

¹⁶ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 35.

¹⁷ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 289.

¹⁸ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 286.

France.”¹⁹ This effort, combined with the German loss of their early-warning network, “substantially reduced the exposure of RAF bombers to both night fighters and flak.”²⁰ Despite local tactical success, the mobility inherent in the relatively small anti-aircraft artillery pieces made suppression difficult, as pilots had to visually spot the guns prior to attacking them. The low-level tactics associated with strafing flak guns were exceedingly risky, and the cost often exceeded the payoff of destroying the guns. The Germans made suppression of the weapons even more difficult by building immense concrete blockhouse towers. The towers, usually surrounding high-value targets such as Berlin, made for exceedingly difficult targets. The Germans were also able to replace destroyed artillery pieces at an impressive rate all the way up to the end of the war. In 1944, they produced 1,245 88-mm guns in the first quarter, 1,452 in the second, 1,512 in the third, and 1,724 in the fourth.²¹ Suppression of German flak in an effort to gain an offensive advantage was not an optimal use of resources, nor was it a prudent balance of risk and reward.

Window

The Allies realized the defensive advantages that flak and an early-warning radar network provided for the Germans. In an effort to maintain an offensive advantage, British physicists such as Reginald Victor Jones devised a rather simple way of deceiving the early-warning network by saturating the radars with returns. By dispensing clouds of foil strips cut to one-half the length of the target radar’s wavelength, the Allies hoped to disguise offensive strike packages. The technology was first put to use on the night of 25 July 1943 over Hamburg. Ronald W. Clark explains the results: “bomber losses, instead of the expected five percent, were dramatically cut to roughly a half per cent.”²² The technology proved its offensive utility when it was put to use during the fake landing in Calais during the D-Day invasion. The Allies dropped Window over the English Channel by flying precise box patterns that moved towards the coast at approximately seven knots or the same speed that landing craft could move through the water. The Allies optimized

¹⁹ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 270.

²⁰ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 271.

²¹ Westermann, *Flak: German Anti-aircraft Defenses, 1914-1945*, 273.

²² Clark, Ronald W. "The Rise of the Boffins." London: Phoenix House, Ltd., 1962, 202.

the jamming and Window employment to avoid completely masking the fake invasion fleet. The planners intended to make it difficult but possible for the highly trained German radar operators to detect the small fake fleet. The strategy was to deceive the operators into thinking they could see only the leading landing craft and assume the main invasion was heading for Calais.²³ In reality, the Germans were merely seeing a small decoy fleet covered by jamming and Window from the air. The technique was so effective that the first notification of the actual invasion fleet off Normandy came from German coastal-defense troops hearing the sounds of landing craft departing their mother ships, not from radar sites along the coast. The Window technology assisted in maintaining airpower's offensive advantage in the face of a radar-based early warning network. The successful invasion sealed Germany's fate. She was crushed in a large pincer with the Red Army in the East and the Allies in the West.

Korea

Due to the nature of nuclear weapons and the Soviet threat, the Korean War provided few new technologies that altered the offense-defense balance with respect to aerial attack. Because of this, the American military and the United Nations used World War II-era technology to combat North Korean defenses. According to Larry Davis, "North Korea had extensive nets of radar-directed anti-aircraft guns and searchlights, which proved quite accurate against the vintage B-29. Out came all of the old World War Two RCM [Radio Counter Measures] —jammers, chaff, ferret aircraft and radar-busting attack aircraft."²⁴ With old technology and limited interest in research and development into new equipment, the Allies were left to rely on proven World War II strategies and tactics to combat North Korean air defenses.

The Korean War provided interesting examples that parallel modern thinking about suppression of enemy air defenses. United Nations aircraft could not avoid the early-warning radars in North Korea with their vast detection ranges. Due to the immense numbers of enemy radars and limitations in new technology, suppressing them would have little effect. Destruction was the only option left if U.N. leaders hoped to

²³ Clark, "The Rise of the Boffins." 230.

²⁴ Davis, Larry. *Wild Weasel: the SAM suppression story*. Squadron/Signal Publications, 1993, 6.

degrade the North Korean air-defense network. With limitations on funding for new technologies, the Americans turned to innovative strategies to suppress the North Korean systems. Craig C. Hannah explains, “using the same tactics that their predecessors had employed against the Japanese, the modified [A-26] Invaders flew missions to destroy North Korean radar sites. The APA-24 receiver would first acquire an enemy radar signal and then direct the pilot toward the hostile transmitter. After locating the radar, the Invaders would strafe, bomb, or rocket the site.”²⁵ This example shows the tendency for leaders to fall back on legacy technologies and strategies when confronted with a new conflict. Luckily for the United Nations, the North Koreans were operating with equipment similar to what the Allies encountered during World War II. The rapid pace with which technological advancements alter the offense-defense balance makes this an exceedingly risky strategy. Leaders must be extremely wary of relying on old technology, paradigms, and strategies when assessing an enemy air-defense system and making assumptions about the status of the offense-defense balance. Great care must be taken, as the first feedback concerning poor assumptions may come only through high loss rates at the hands an enemy air-defense system utilizing emerging technologies.

Additionally, the lack of technological innovation during the Korean War proves illuminating of the offensive utility of airpower. The North Korean’s only real innovation during the war was the adoption of jet fighters from the Soviet Union. This measure merely brought technological parity with the United States and its fleet of F-86s. The United States had the advantage in numbers as well as training in the skies over North Korea. Regardless of this fact, the point remains that the offensive utility of airpower was proven in the Korean War as the United States was afforded freedom of action over the peninsula. The United States used the airplane offensively while the North Koreans used the tool defensively. The North Koreans were able to mount limited successful defenses with their jet aircraft but only in small areas such as Mig Alley, a small area of Northwestern Korea extending south from the Yalu River halfway to

²⁵ Hannah, Craig C. *Striving for Air Superiority: The Tactical Air Command in Vietnam*. Texas A&M University Press, 2002, 76.

Pyongyang.²⁶ As a result, the rest of the country was left relatively defenseless against United States offensive airpower.

The birth of modern air-defense thinking, technology, and suppression techniques started during the great power conflict of World War II and continued through the Korean War. Rapid advancements in technology contributed to continuous shifts in the offense-defense balance with respect to air defenses. These shifts caused military leaders to change force structures, allocate resources, and alter leadership reflecting changes in thinking about suppression of enemy air defenses. Radar technology, initially employed during the Battle of Britain, contributed to the defeat of the Luftwaffe over the English Channel. The lack of a suppression strategy by German offenders shows the effectiveness of the technology in a defensive role. Anti-aircraft artillery proves to be a significant obstacle to air power but fails to remove the offensive utility of the air weapon.



²⁶ Zhang, Xiaoming, *Red Wings Over the Yalu: China, the Soviet Union, and the Air War in Korea*. College Station: Texas A & M University Press, 2002, 93.

Chapter 3

Vietnam War through Operation Desert Storm

A Commander who tries to win—or not lose—without air superiority is trying to do what no one has done before.

John A. Warden III

After World War II and the Korean War, modern air-defense thinking continued to advance in an attempt to keep pace with rapid technological advancements. Challenges to the offensive nature of airpower continued, much like it did from World War II to the Korean War, as a result of the continuous search for an advantage. With a solid understanding of the birth of modern strategic thought on air defense, one can continue to see how new technologies as well as improvements on old technologies seek to challenge air powers primacy. Did the introduction of guided surface-to-air missiles (SAMs) in Vietnam enable a shift to the defensive? If so, how did the United States respond? By examining the United States' reaction to SAMs one can begin to see how technological foresight is the only way to avoid unnecessary losses in future conflicts. Did technologies such as Radar Homing and Warning (RHAW) systems on fighter-bombers shift the balance back to the offensive? The same question can be posed of US efforts at developing defensive electronic warfare systems. They highlight the unique ability of the technology to shift the balance depending on the context within which it is used.

This chapter also seeks to determine how effectively anti-radiation missiles enabled the US to maintain an offensive-airpower advantage. The United States paired unique strategic thinking and tactical execution with these three new technologies in an attempt to restore advantages to the offender. The enemy responded through the introduction and refinement of integrated air defense systems (IADS) that sought to

regain a defensive advantage. Stealth technology and precision weapons developed before the Gulf War represent the final technologies examined in this chapter. They attempted to shift the balance back in favor of the offense, and may have succeeded.

Surface-to-Air Guided Missiles

Surface-to-air guided missiles presented armed forces with an opportunity to dramatically shift the balance towards the defensive. This fact is clear when examining the introduction of the SA-2 missile system into the Vietnam War. Before the introduction of the SA-2, North Vietnam relied on anti-aircraft artillery and a handful of outclassed Russian-supplied fighter aircraft. When the United States introduced the F-4 into the Vietnam conflict the North Vietnamese knew the majority of their fighter fleet, composed of Korean War legacy MiG-17s, was obsolete. The capabilities of the F-4 had two effects on the North Vietnamese. The first is that they sped up the introduction of the MiG-21 into the combat arena. The second development was the introduction of the SA-2 into the North's arsenal. Dan Hampton explains, "American dog fighting skills were well founded and the VPAF [Vietnam People's Air Force] knew they'd never prevail in an even air-to-air fight. This was precisely why Hanoi, several months earlier, had insisted upon receiving the latest surface-to-air missile technology from the Soviet Union."²⁷ Additional factors highlight Hanoi's desire to capitalize on surface-to-air missiles. Initiation of the Rolling Thunder strategic-bombing campaign in March of 1965 put pressure on Hanoi, which looked to speed up surface-to-air missile procurement. Hampton argues that "two direct results occurred [from the initiation of bombing]: first, SA-2 missile sites were to be constructed immediately and manned by Soviet advisors until the Vietnamese were trained. Second, shipments of fighter aircraft and training for pilots would be greatly accelerated."²⁸ North Vietnamese and Russian strategic decision makers were keenly aware of the potential of the SA-2 missile system to shift the balance towards the defense in North Vietnam. Hanoi capitalized on the political sensitivities and

²⁷ Hampton, Dan. *The Hunter Killers: The Extraordinary Story of the First Wild Weasels, the Band of Maverick Aviators Who Flew the Most Dangerous Missions of the Vietnam War*. New York, NY: William Morrow, 2015, 58.

²⁸ Hampton, *The Hunter Killers*, 56.

the reluctance of the United States to inadvertently kill Russian advisors to set up a sophisticated air-defense network in the midst of a strategic bombing campaign.

The SA-2 is a Soviet-designed-and-built missile system that saw its first operational combat experience against the United States over Russia and Cuba. The system uses a powerful radar array, code named FAN SONG, to track enemy aircraft. With a stable radar track, computers determine if the enemy aircraft will be within the missile's kinematic range for an intercept. When a firing solution is obtained, the system launches a GUIDELINE missile and the FAN SONG radar transitions to a missile-guidance waveform. The guidance beam provides a signal for the missile to follow en route to the target. NATO intelligence assets knew about the system as early as 1953 but had little insight into its utility until 1960.²⁹ The SA-2 scored victories on a U-2 spy plane (piloted by Francis Gary Powers) over Russia in 1960 as well as another U-2 piloted by Rudolf Anderson over Cuba in 1962. The United States and its allies were slow to recognize the decisive effects that the SA-2 brought to the battlefield. Full understanding of the system and its effects on the offense-defense balance would not come until 1965 in Southeast Asia. Three years after Rudolf Anderson's U-2 was shot down over Cuba, in the spring of 1965, the North Vietnamese and the Russian military began deploying the SA-2 across North Vietnam.³⁰

The first successful kill by an SA-2 in Vietnam came quickly after the system became operational. The Soviets designed the system to defend against approaching United States nuclear-armed bombers, a target that does not maneuver aggressively. Hence, the system lacked a robust capability to engage the agile fighter-bombers often encountered by the North Vietnamese. Despite these design limitations, the presence of the SA-2 in theater caused significant degradation in offensive operations. Hampton illuminates, "it could be argued that the real lethality of the SAM lay not with the missile itself, but in the threat of the missile, which would force fighter-bombers to jettison their bomb loads or drive them down into anti-aircraft artillery range."³¹ Despite knowing

²⁹ Davis, Larry. *Wild Weasel: the SAM Suppression Story*. Squadron/Signal Publications, 1986, 6.

³⁰ Davis, *Wild Weasel: the SAM Suppression Story*, 7.

³¹ Hampton, *The Hunter Killers*, 91.

about the system since 1953 and seeing its devastating effects over Cuba and Russia five years earlier, the US was caught off guard by its appearance in North Vietnam. Hampton explains, “in addition to Washington’s shock and disbelief, the events over the Red River on July 24, 1965 [the first US loss to an SA-2] produced two immediate results. Foremost, in long term, the tragedy led to a revolution in combat aviation,”³² confirming the defensive advantages that the surface-to-air missile provided. The United States had known about the system for well over 10 years and had even lost aircraft to the technology but did not fully understand the shift towards the defensive that the surface-to-air missile provided. It took a significant, shocking loss in combat to spur the type of revolution required to defeat the system.

Radar Homing and Warning Systems

After the first loss of a US airplane to the SA-2 in July of 1965, the United States finally realized the shift in the offense-defense balance enabled by surface-to-air missiles. Once recognition of the shift resonated at the strategic level, the United States started an aggressive technology-based effort focused on tipping the balance back towards the offense. The first technology introduced by the United States, called Radar Homing and Warning systems, gave pilots and weapon-system officers audio and visual cues when enemy radars were operating in their vicinity. The installation of the RHAW systems on F-100 fighter-bombers was the start of a comprehensive program focused on limiting the defensive advantages of the SA-2 in Vietnam. Davis explains, “these recommendations included installation of one of the new RHAW sets in several F-100F pathfinder aircraft under the code name Project Ferret (later changed to Project Wild Weasel after it was found that Ferret had been a World War Two project).”³³

Before the installation of the RHAW equipment, pilots relied on two primary methods of identifying when an enemy surface-to-air missile system was a threat. The first method was to simply spot the missile after launch with the naked eye. The SA-2 GUIDELINE missile, nicknamed the flying telephone pole by Vietnam-era pilots, has a large main body, measuring over 35 feet in length. The two-stage rocket motor produces

³² Hampton, *The Hunter Killers*, 13.

³³ Davis, *Wild Weasel: the SAM Suppression Story*, 8.

a large dust and smoke cloud at launch, giving aircrews a decent visual indication of launch. The missile flies at well over the three times the speed of sound. Even if a pilot was lucky enough to spot the launch and determine that the missile was targeting his aircraft, he had only seconds to react. If there was any weather obstructing the launch site, or the pilot missed the initial launch of the SAM, he could have little hope of defending against the threat. The United States attempted to mitigate this weakness by fielding aircraft with specialized equipment designed to intercept the signals from the enemy radar. When the aircraft spotted enemy emissions from threat radars, the crew would warn the strike package by voice over the radio. This method worked well but did not provide accurate information on which specific aircraft the missile was targeting leaving it to the individual fighter-bomber pilots to sort out. A better way to get information on SAM launches was needed, and the United States turned to technology to solve the problem. Installing RHAW sets initially on the F-100F and then the entire tactical fighter fleet was a step towards giving pilots the information they needed to defeat enemy threats. The RHAW sets represent a small step towards shifting the balance back towards the offensive.

Podded Electronic Warfare Systems

The next technological advancement that the United States incorporated in an attempt to bolster the offense in the face of North Vietnamese SA-2s was the podded self-defense jamming system. Similar to the above example, the United States initially employed dedicated-jamming aircraft to cover strike packages en route to their targets. The strategy of dedicated-jamming platforms stemmed from Strategic Air Command thinking about how to get nuclear-equipped bombers through Russian defenses on the way to their targets. Hampton explains, “as heavy bombers cannot rely on maneuvering to defeat a threat, the Strategic Air Command had long relied on electronic warfare and countermeasures to increase survivability for its planes.”³⁴ The jamming aircraft would intercept the signals from enemy threat radars and re-transmit them at a very high power in an effort to mask the strike package’s approach. Problems with this method immediately became apparent. As the strike package got closer to the threat radar and

³⁴ Hampton, *The Hunter Killers*, 94.

farther away from the friendly jammer, the FAN SONG radar was able to overpower the jamming and target the strike package. Once again, the United States turned to technology in an effort to shift the offense-defense balance. In 1967, Tactical Air Command mandated that all tactical aircraft carry electronic-counter-measure pods on combat sorties.³⁵ The combination of jamming pods and RHAW equipment significantly reduced the danger caused by the SA-2. What was needed was a way to kill the SAM, or at least permanently remove its ability to target friendly aircraft.

Anti-Radiation Missiles

The next technological advancement incorporated into the Wild Weasel program provided a significant shift towards the offensive. Guided anti-radiation missiles, first employed in Vietnam, gave fighter aircraft in Tactical Air Command the ability to offensively strike back at the SA-2 missile system without the need for dangerous low-level over-flight tactics. The AGM-45 Shrike missile reached Vietnam in May of 1966. The missiles, initially employed only on the F-100F, tracked enemy radar emissions and translated the signals into guidance commands for the weapon. As long as the enemy radar remained in a transmit mode, the missile guided precisely to the critical component of the SAM system, the target-tracking and missile-guidance radar set. If the SAM operator turned the radar off during the flight of the Shrike missile, the weapon was guaranteed to miss. The North Vietnamese quickly exploited this weakness by delaying their radar emissions until the target was at very close range and then quickly engaging the target and turning the radar off to avoid potential AGM-45 hits. This tactic perpetuated the cat-and-mouse game between the offense and the defense. The United States responded with the General Dynamics AGM-78 standard missile. The AGM-78 is a derivative of the Navy's Tartar surface-to-air missile adapted for anti-radiation air-to-ground attack.³⁶ The missile had significant advances in technology including improved electronics, a more sensitive receiver, a larger rocket motor, and a memory function. These advancements allowed aircrew to launch the missile farther away, the missile would arrive at its target sooner, and if the enemy radar turned off during the

³⁵ Davis, *Wild Weasel: the SAM Suppression Story*, 8.

³⁶ Davis, *Wild Weasel: the SAM Suppression Story*, 23.

engagement, the missile would guide to the last known location of the threat antenna. Even if the missile did not score a direct hit, the explosion near the SAM provided a point of reference for the Wild Weasel teams to search for follow-on targets.

Pairing Strategy with Technology

Senior United States Air Force leaders began to realize that technology alone could not effectively shift the balance toward offensive airpower. Technology needed to be paired with sound supporting strategy in order to be effective. The Vietnam conflict refined efforts to marry a sound SEAD approach to SAMs with rapidly emerging technology. The dedicated SEAD forces embodied in the Wild Weasel hunter-killer teams show that leaders did indeed recognize, although late, the shift towards the defense that surface-to-air missile technology enabled. The training of the initial Wild Weasel aircrews started at Eglin AFB. The teams equipped their F-100F aircraft with the new RHAW technology and started training against fake SA-2 emitters on the Gulf Coast. After only a few months of training, the crews took their modified airplanes and strategy to Southeast Asia. On 28 November 1965, the dedicated SAM-killing teams, the Wild Weasels, began flying orientation missions near the North Vietnamese border.³⁷ The new technology proved to be difficult to operate effectively in theater, justifying the aircrew's specialized training. Senior United States Air Force leaders recognized the importance of the specialized nature of the SAM-killing mission. The United States started flying these missions, code named IRON HAND, in December of 1965. The teams quickly adapted their tactics and achieved the first SA-2 kill on 22 December 1965.

The first verified kill of an SA-2 demonstrated the utility of the new technology and strategy providing legitimacy to the SEAD enterprise. The IRON HAND missions became part of standard operations in North Vietnam. Davis explains, "normally the Weasels went in ahead of the strike force to ferret out SAMs, watch for AAA patterns, and check the weather near the target."³⁸ The tactics allowed the Wild Weasels to gather information about the most critical and dangerous portion of the strike aircraft's mission, the run-in to the target. With detailed and timely intelligence, the risk to the strike

³⁷ Davis, *Wild Weasel: the SAM Suppression Story*, 11.

³⁸ Davis, *Wild Weasel: the SAM Suppression Story*, 12.

packages decreased. The Weasels further reduced risk by forcing the SAMs off the air through kinetic and non-kinetic means. Davis continues, “it didn’t matter whether you blasted a SAM site to bits under direct attack, or merely forced him off the air—the results were the same. The SAM was not there to bother the strike force.”³⁹ The strategic thought behind these methods was born during the Korean War, refined during Vietnam, and is still applied by SEAD forces today. Davis describes both the Vietnam and the Korea strategy when he articulates, “the idea being for the ABDULLAH [specialized electronic support] aircraft to locate the radar by homing in on the beam until acquiring the site visually. The ABDULLAH aircraft would then mark the site with smoke bombs or rockets.”⁴⁰ The hasty nature of the United States’ response to the SA-2 in Vietnam with the Wild Weasel IRON HAND missions, however, highlights a failure to foresee the shift in the offense-defense balance that the SA-2 provided. Furthermore, the congruency in tactics from Korea to Vietnam shows that commanders tend to fall back on proven strategies from previous wars to solve problems of current wars. With accurate intelligence and forethought, commanders can anticipate the effects of new technology, or at least consider the possible impacts.

Integrated Air Defense Systems

Integrated air-defense systems (IADS) are a combination of technologies that can alter the offense-defense balance in favor of the defender. Integrated air-defense systems first demonstrated their utility during World War II with the Germans attempting to implement a system as early as 1939. Edward Westermann explains, “the West Wall (in Germany in 1939) was also one of the very first attempts to construct an integrated air defense network for coordinating the operations of ground-based air defenses with an interceptor force along a broad front.”⁴¹ The British also implemented an air defense system. England’s victory in the Battle of Britain is a fine example of how an integrated air-defense system can contribute to a dramatic shift in the offense-defense balance. The North Koreans and the North Vietnamese operated simple air-defense systems

³⁹ Davis, *Wild Weasel: the SAM Suppression Story*, 12.

⁴⁰ Davis, *Wild Weasel: the SAM Suppression Story*, 13.

⁴¹ Westermann, Edward B. *Flak: German Anti-aircraft Defenses, 1914-1945*. University Press of Kansas, 2001, 80.

highlighting the massive resources required to build and implement an effective IADS. Hamilton explains, “using what was available in 1965, the North Vietnamese constructed a rudimentary integrated air defense system.”⁴² The North Vietnamese augmented their relatively modest network of early-warning radars with time-tested methods of detection such as binoculars, noise signatures, and naked eyeballs. In an effort to supplement the IADS, the North Vietnamese employed mobility strategies with their air-defense equipment to enable a defensive advantage. Hampton clarifies, “they [the North Vietnamese] knew that if it wasn’t able to move and hide, it would be destroyed. Because they moved frequently, and began limiting FIRECAN [a radar used to cue anti-aircraft artillery] and FANSONG radar emissions, locating operational SAM sites became highly uncertain.”⁴³ This fact further reinforces that Hanoi recognized the shift towards the defensive that an IADS provided but simply could not afford to optimize the system.

Iraq, unlike Vietnam, both respected the shift to the defensive that an optimized IADS provided and could afford such a system. Because of Russian influence, experience in the Iran Iraq war, and observations of the Vietnam and Israeli wars Baghdad invested in a network of 500 radars located in no less than 100 sites augmented by 8,000 anti-aircraft guns, 4,000 of which were centered around Baghdad.⁴⁴ The Iraqi IADS relied on a French-built system called KARI.⁴⁵ The KARI system distilled the information from the vast early-warning network, coordinated the actions of the IADS, and facilitated decision-making for the Iraqi leadership.⁴⁶ In sum, the Iraqi IADS made up of one of the most capable and formidable defensive systems in existence. It would take significant technological advancements on the part of the United States in order to maintain an offensive advantage. The technologies that would eventually enable the swift defeat of the Iraqi IADS were stealth and precision weapons combined with a revolution in targeting strategy.

⁴² Hampton, *The Hunter Killers*, 98.

⁴³ Hampton, *The Hunter Killers*, 98.

⁴⁴ Cohen, Eliot A. *Gulf War Air Power Survey*. US Government Printing Office, Washington DC, 1993, 218.

⁴⁵ KARI is Iraq spelled backwards in French.

⁴⁶ Cohen, *Gulf War Air Power Survey*, 218.

Stealth Technology

Stealth technologies enabled a dramatic shift towards the offensive even in the face of an extremely capable Iraqi air defense system. Thoughts about stealth technology seem to have developed because of B-52 losses during LINEBACKER II missions, US observations of the Yom Kippur War, and shared lessons from the 1982 Falklands War. The F-117 possessed a specific shape and coatings that hid it from the radars that made up Iraq's early-warning system. The early-warning network built a track on an aircraft and pushed the track up to the KARI system, enabling Iraqi leaders to make decisions on how to deal with the threat. The design of the F-117 significantly delayed detection by these types of early-warning radars. If the Iraqi KARI system never received information from the early-warning radars about an incoming flight of F-117s, it never notified the missile batteries to start engaging the track. The nonexistent reaction from the KARI system provided stealth aircraft with relatively unobstructed paths to their targets, requiring minimal outside support. John Warden explains, "we had stealth aircraft that penetrated by themselves and thus made it possible to bring many targets under simultaneous attack."⁴⁷ The F-117 did not require the massive support package that traditional fighters or bombers would have needed to be successful over Baghdad. Stealth technology essentially changed the definition of mass and concentration as American aircraft could bring many critical and heavily defended Iraqi targets under simultaneous attack, causing significant paralysis in the system. Warden continues, "mass and concentration are as important as ever, but stealth and precision have allowed us to understand these concepts in terms of their effects, not on the number of people or machines committed."⁴⁸ The effects-based approach to combat against the Iraqis permitted very few aircraft to paralyze the air-defense system, allowing for significantly reduced risk to traditional, non-stealth strike packages.

Precision Weapons

Precision weapons were the next technology that significantly privileged the offense. Precision weapons allowed for a very high probability of kill against targets that

⁴⁷ Warden, John A. *The Air Campaign: Planning for Combat*. iUniverse, 1998, 148.

⁴⁸ Warden, *The Air Campaign: Planning for Combat*, 160.

would normally take multiple attacks by non-precision weapons. Precision weapons allowed a single aircraft to successfully attack a target that may have taken multiple strike packages several days to destroy with non-precision weapons. Warden emphasizes the importance and utility of precision weapons in Iraq when he says, “most importantly of all, we had bombs that had a very high probability of hitting that against which they were aimed. Precision has changed the face of warfare.”⁴⁹ Precision weapons allowed the coalition to simultaneously attack, in parallel, Iraqi IADS, leadership targets, command-and-control, and fielded forces. Without precision weapons, the offense-defense balance would have mandated a series-based approach where the coalition first destroyed the IADS system then moved on to other targets. Precision weapons, combined with stealth, allowed the coalition to mass against nearly every target set at one time. The result was the swift defeat of Saddam Hussein’s forces with the ensuing ground offensive.

The AGM-88 High Speed Radiation Missile (HARM) significantly improved upon the concepts inherent in previous SAM-killing missiles. Owen explains the utility of the weapon, “the HARM is designed to detect, home in on, and destroy radar emitters such as early warning, acquisition, and tracking radars operating throughout a wide range of frequency bands.”⁵⁰ The HARM saw action in nearly every conflict after its introduction into the United States inventory. It was a significant enabler to success in Iraq, suggesting that anti-radiation missiles can indeed shift the offense-defense balance towards the offense. The Gulf War Air Power Survey reinforces this point when it states, “an analysis of the effectiveness of the suppression of enemy air defense (SEAD) mission on radar-directed defensive systems shows a clear correlation between high-speed anti-radiation missile (HARM) shots, and the reduction in Iraqi radar emissions.”⁵¹ Although it took nearly 20 years, the technological advancements in anti-radiation missiles proves that dedicated SEAD forces can make a difference.

Caution must be applied when assigning roles previously vetted in wartime to new stealth platforms. Weapons systems such as the Joint Strike Fighter and the F-22

⁴⁹ Warden, *The Air Campaign: Planning for Combat*, 148.

⁵⁰ Owen, Robert C. *Deliberate Force. A Case Study in Effective Air Campaigning*. Air University Press, Maxwell AFB AL, 2000, 267.

⁵¹ Cohen, Eliot A. *Gulf War Air Power Survey*. US Government Printing Office, Washington DC, 1993, 239.

cannot be expected to perform in similar ways to the F-117 over Iraq. Recent technological advancements, discussed in the next chapter, show that yet another shift in the offense-defense balance has occurred. This most recent shift will necessitate a rethinking of current paradigms. Owen supports this when he states, “in future limited conflicts, against sophisticated IADS or highly defended target complexes, we must alter the single-strike mentality of war planners to a more adaptive employment of tactical assets engaging in multiple-target attacks.”⁵² Modern strategists must recognize the shift in the offense-defense balance that recent technological advancements have enabled. Without a recognition and shift in thinking, the United States will endure unacceptable losses using old paradigms in the SEAD environment.

As a result of the continued search for an advantage provided by technology, air defenses challenged the offensive use of airpower from the Korean War to the Gulf War. Examining these shifts in the offense-defense balance can give strategic thinkers insight into what future shifts may mean for an Air Force. The introduction of guided surface-to-air missiles in Vietnam highlights a dramatic shift to the defensive. The United States effectively responded to the shift towards the defense but in a reactionary manner. The use of RHAW systems on US fighter-bombers effectively shifted the balance back towards the offensive. Padded defensive jamming systems had a similar effect on the balance. Anti-radiation missiles, employed by tactical aircraft also served to shift the balance back towards the offensive. The United States successfully paired unique strategic thinking and tactical execution with these three new technologies that further enabled the offensive. In response, enemies such as Iraq, introduced and refined technologically advanced integrated air defense systems. Although IADS appeared to shift the offense-defense balance back towards the defensive, the United States responded with stealth technology and precision weapons. Both of these technologies significantly shifted the balance back to the offense. Historically, it appears that the characteristics of mobility, concentration, and freedom of action equip offensive airpower with inherent advantages. Douhet appears to have been right, but for some of the wrong reasons.

⁵² Owen, *Deliberate Force. A Case Study in Effective Air Campaigning*, 257.



Chapter 4

Present Day

It was the same after every war: the country sent everyone home, vowed never to fight another war, and then when the inevitable war came along, brave young Americans would soak the soil of some foreign land with their blood for sheer lack of preparation.

-James Kitfield

This chapter attempts to answer questions about how modern technology affects SEAD when adversaries have similar capabilities. How does modern stealth differ from that of the F-117? If there are indeed differences, how does modern stealth seek to enhance the “inherently offensive” nature of airpower? This chapter seeks to answer similar questions about modern advanced surface-to-air missile systems built to counter emerging offensive technology. If advanced modern SAMs serve to shift the offensive-defensive balance in favor of the defense, do modern electronic attack, airborne decoys, and swarming technologies serve to re-establish the air weapon as a viable offensive tool? To avoid the peril that James Kitfield outlines in the quote above, strategic leaders must continually examine these and other emerging technologies with an eye for how they change the utility of airpower.

Modern Stealth

Modern stealth aims to improve upon the advantages discovered through the HAVE BLUE¹ program and the F-117. Modern stealth aircraft retain the same basic advantages that low observability provides but incorporate additional technological advancements such as radar, counter measures, electronic warfare equipment, and missile-warning systems to further increase their offensive utility. More important than the additional technologies added to modern stealth aircraft are the design philosophies behind such platforms. A basic equation is commonly used to determine the range

¹ HAVE BLUE was the code-name for the aircraft that preceded the Lockheed Martin F-117. The vehicle was a technology demonstrator that served as a proof of concept for low observable technology.

(Rmax) at which a radar will detect a platform with a given radar cross section (RCS) represented by σ in the equation below.²

$$R_{\max} = [P_t G^2 \lambda^2 \sigma / (4\pi)^3 P_{\min}]^{1/4}$$

Modern stealth aims to drive Rmax to the smallest value possible by manipulating the only variable that designers have control over in the equation, σ . P_t is the transmit power of the radar, G is the antenna gain, λ is the wavelength, and P_{\min} is the minimum detectable signal, all of which are ground or air-based threat characteristics and not controllable by the stealth-platform designers. Radar cross section is highly dependent on many things, but the characteristics of the threat radar from which it is measured are the most important during the design phase. σ in the radar equation depends on target geometry, target surface-material composition, orientation of the radar antenna relative to the target, angular orientation of the target to the radar antenna, frequency of the electromagnetic energy, and radar antenna polarization.³ The simplified formula for calculating the RCS of a curved edge, commonly found on aircraft, illuminates the relationship between frequency, wavelength, and RCS.⁴

$$\sigma = a\lambda/2\pi$$

λ in this equation equals the wavelength of the transmitting radar.⁵ a is the radius of the edge contour. For a simple, curved edge, as the wavelength of the threat radar increases; so does the RCS. Platform designers must make an educated guess as to what electromagnetic frequency and polarization the future threats to the low-observable aircraft will potentially employ. During the design phase of low-observable platforms,

² Knott, Eugene F., Shaeffer, John F., Tuley, Michael T., "Radar Cross Section." Second Edition, SciTech Publishing, 2004, 46.

³ Zikidis, Konstantinos, Alexios Skondras, and Charisios Tokas. "Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies." *Journal of Computations & Modeling* 4, no. 1, 2014, 130.

⁴ Knott, "Radar Cross Section." 562.

⁵ $\lambda = c/f$ where c is the speed of light and f is the frequency of the radar signal.

key threats are identified, and the designers then optimize the aircraft shape and coatings to minimize reflections of those wavelengths and polarizations. By optimizing the platform for a specific range of wavelengths and polarizations, the designers make compromises that result in the aircraft being stealthy over a very specific region of the electromagnetic spectrum. Some platforms will be stealthier when facing a lower-frequency (larger wavelength) threat such as early-warning radars. Other platforms will be optimized to delay detection by higher-frequency (smaller wavelength) radars such as target-tracking or missile-guidance beams. Many factors go into the design of an aircraft, but the philosophy behind low radar-observability shows how modern stealth attempts to regain the offensive advantage by breaking the enemy kill chain at the point where the aircraft is the most invisible.

Different attack platforms are optimized to focus on defeating a specific part of an enemy-air-defense system. A large platform, such as a bomber, may be designed to hide from low-frequency early-warning radars. Dave Majumadar, the defense editor for *The National Interest*, explains, “a larger stealth aircraft like the Northrop Grumman B-2 Spirit, which lacks many of the features that cause a resonance effect, is much more effective against low-frequency radars than, for example, an F-35 or F-22.”⁶ Early-warning radars usually operate at the lower end of the electromagnetic spectrum in frequency and seek to achieve superior detection range while sacrificing accuracy. A platform designed to break the kill chain at the early-warning stage of engagement should be optimized to be almost undetectable by low frequencies. If the early-warning radars never see the low-observable platform, they will fail to report the track to a higher echelon of command and control. If the early-warning radars never detect and hence fail to report the platform, air-defense systems will have no reason to activate their target-tracking and engagement radars, thus breaking the enemy kill chain.

On the other end of the spectrum, small fighter-sized aircraft are often optimized to break the kill chain at a different point. Fighter-sized low-observable aircraft are often optimized to defeat higher frequency target-tracking and missile-guidance radars often

⁶ Majumdar, Dave. “Revealed: China’s Radars Can Track America’s Stealthy F-22 Raptor.” *Nationalinterest.org*. <http://nationalinterest.org/blog/the-buzz/revealed-can-chinas-radars-track-americas-stealth-f-22-15261> (accessed March 1, 2017).

found on enemy fighters and surface-to-air missile systems. John Patterson explains why this is true, “most fighter aircraft operate in the X- and Ku-bands because accurate target locations can be provided with less power and in a much smaller package. Many fighters operate in the 1-2-in. wavelength of the X-band because atmospheric attenuation is reasonably low and very good angular resolution can be achieved with an antenna small enough to fit in a fighter nose.”⁷ The low-frequency early-warning radars have few problems detecting a fighter-sized target optimized for high frequency stealth. This means that the early-warning radars will detect the stealth fighters and pass the information up to higher echelons of command and weapons control. In turn, the higher-frequency tracking and engagement systems will activate in an attempt to engage the target. The tracking and engagement phase is where the fighter, optimized against higher-frequency threats, seeks to break the kill chain. Konstantinos Zikidis, in the *Journal of Computations and Modeling*, explains, “the scope is the break of the killing chain: even if the F-35 is detected by a surveillance radar, it will not be easy to engage by a fire-control radar, which usually operate in the X or Ku bands.”⁸ In other words, the air-defense system will know full-well exactly where the low-observable fighter is located but will be unable to do anything about it.

Herein lies the advantage of modern stealth in shifting the offense-defense balance. The technology inherent in modern stealth aircraft allows them to be optimized to break the enemy kill chain at specific points. This technology allows planners to optimize platform use based on the specific threats that the enemy is expected to employ against the low-observable characteristics. With multiple kill-chain-breaking options inherent in the F-22, F-35, B-2, and eventually the B-21, mission planners are afforded opportunities to reduce risk. These opportunities can be tailored to the specific situation with the intent of preserving the offensive advantages of airpower. Douhet appears again to have been right, for some of the wrong reasons.

⁷ Paterson, John. "Overview of low observable technology and its effects on combat aircraft survivability." *Journal of Aircraft* 36, no. 2, 1999, 381.

⁸ Zikidis, "Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies." *Journal of Computations & Modeling* 4, no. 1, 2014, 144.

Advanced Surface-to-Air Missiles

The intent of this section is not an exhaustive capabilities-study of modern surface-to-air missile systems and low-observable aircraft. Examination of the basic principles behind long-range advanced missiles illuminates their defensive advantages, regardless of systems-specific capabilities. Much of the data about currently fielded and future SAM technology remains closely held as national secrets. Open-source reporting, however, provides sufficient information with which to gain insight into the systems' defensive attributes. As mentioned above, stealth aircraft are not completely invisible to ground or air-based radar technology. The stealth properties of the aircraft merely reduce the range at which threat radars can detect the low-observable platform. The basic radar equation introduced above can be re-written to show that as range (R in the equation) to the transmitter decreases the power received (P_{rec}) by the antenna after reflecting off the target increases at an exponential rate.

$$P_{\text{rec}} = P_t G^2 (\sigma/4\pi R)^2 (\sigma/4\pi R^2)$$

Said in a different way, this means that no matter how stealthy an airplane is, it will eventually be detected by a radar emitter if it gets close enough. This phenomenon was demonstrated with disastrous results when in 1999 a Serbian SA-3 battery shot down a U.S. F-117 over the Balkins. In this case, the latest in high technology was defeated by a legacy system that had been in service for well over 35 years. Additional factors contributed to the downing of the Nighthawk, but the consequences explained by the radar equation enabled the successful SA-3 engagement.

Since the days of the SA-2 and SA-3, technological advances have improved nearly every aspect of the surface-to-air-missile enterprise. The two categories addressed in this work are capability and range. Some of the most important capability improvements include increased ability to successfully engage moving targets, electronic counter measures, the ability to target ballistic missiles, and the capacity to engage multiple targets simultaneously. These capability enhancements afford the modern surface-to-air-missile system an ability to provide an increasingly strong defense. They also complement each other and are highly dependent upon the context of the situation in

which they are used. These facts make it difficult to gauge their direct impact on the offense-defense balance. Range, on the other hand, provides a tangible method with which to examine modern SAMs' effects on the battlefield. Russian technology is at the leading edge of SAM development. Moscow's systems are proliferated worldwide and often copied by countries like China and North Korea. The Soviet-designed SA-2 has a maximum effective range of up to 58 kilometers (31 nautical miles).⁹ The next evolution of Russian SAM technology came in the form of the SA-6 family of systems. These systems, including the SA-11 and SA-17, offer comparable ranges to the SA-2 but include the ability to attack low-altitude, maneuvering targets. The systems are also extremely mobile as opposed to the traditionally stationary SA-2. The SA-10 family of systems demonstrated a giant leap in both capability and maximum range. The system can engage targets out to 90 kilometers (48 nautical miles) with dramatically improved capability against all types of targets. The next leap in technology came in the form of the SA-20, a system that can launch four different types of missiles depending on the situation. The missiles have ranges of 40 kilometers (21 nautical miles), 120 kilometers (64 nautical miles), 250 kilometers (134 nautical miles), and an impressive 400 kilometers (215 nautical miles).¹⁰ While some of the numbers may be exaggerated in an attempt by Russia to sell these systems, the trend of ever-increasing maximum ranges is clear.

To simplify the discussion, one can examine a notional low-observable platform that in effect reduces the maximum detection and therefore engagement range of a SAM system by 75 percent. Based on the maximum effective ranges from above, this would mean that the notional stealth platform in question could get within 7.75 nautical miles of an SA-2 before the system could engage. It follows that a single SA-2 could defend 189 square miles of territory against the notional stealth fighter.¹¹ The SA-20 offers a starkly different story. Based on 75 percent of the system's maximum effective range, the

⁹ Kopp, Carlo. Technical Report APA-TR-2009-0702, Australian airpower.net, <http://www.ausairpower.net/APA-S-75-Volkhov.html>, accessed 8 March 2017.

¹⁰ Kopp, Carlo. Technical Report APA-TR-2009-0503, Australian airpower.net, <http://www.ausairpower.net/APA-S-400-Triumpf.html>, accessed 8 March 2017.

¹¹ A critical assumption is that the SA-2 could engage the notional platform at all possible altitudes within 7.75 NM of the SAM.

notional low-observable platform could be engaged anywhere within 53 nautical miles of the system. The SA-20 could then defend 8824 square miles of terrain, and the airspace above it, from the notional aircraft. The math is grossly simplified but it illuminates the argument that the increase in maximum effective range inherent in modern SAM systems tips the balance significantly towards the defensive.

The maximum effective range of modern SAM systems illuminates another important concept. The increased range means that a state requires fewer systems to defend the same amount of territory from air attack. An example helps to reinforce this concept. The area of Kaliningrad Oblast, a federal subject of the Russian federation on the Baltic Sea, has a total area of 4402 square nautical miles (5,830 square miles). To defend the territory of Kaliningrad, not including any neighboring airspace or air-defense identification zones, against a notional low observable aircraft would require over 23 SA-2 systems. In contrast, a single SA-20 battery could defend twice the area of Kaliningrad. The reduction in cost associated with organizing, training, and equipping a reduced number of systems is difficult to calculate. However, it appears more economical to defend an area with a reduced number of long-range systems versus a large number of shorter-range systems.

Advanced Electronic Attack

Advanced electronic attack, a new form of jamming, attempts to further reduce the range at which a modern SAM can engage low-observable platforms. Before the advent of modern stealth aircraft like the F-35, the United States employed dedicated electronic attack aircraft in an effort to maintain the offensive advantage. The armed forces traditionally called this type of electronic attack standoff jamming. Standoff electronic attack places the jamming aircraft outside the range of the threat system. Most standoff jammers attempt to overpower or confuse threat radar systems to allow strike aircraft an unimpeded path to their targets. John Haystead, in the *Journal of Electronic Defense* explains how this affects operations against long-range-modern SAMs, “current standoff approaches rely almost exclusively on dedicated AEA [airborne electronic attack] platforms, such as the EA-18G Growler and EC-130H Compass Call aircraft, with high-power, wideband jamming systems. These low density, high-demand systems, however, are intended to primarily operate outside the range of threat systems, so with

the increasing reach of the threat, the effectiveness of these “stand-off” platforms’ high-power jamming is significantly reduced.”¹² The increased range of modern SAM systems reduces the effectiveness of standoff jamming to the point where something else is needed to maintain air power’s offensive advantage.

The alternate strategy to standoff jamming is aptly named stand-in electronic attack. Stand-in jamming usually comes in one of two forms. The first form is a unmanned-flying decoy that will be discussed in the next section. The second form of stand-in jamming uses the strike and/or SEAD aircraft themselves as electronic attack platforms. The F-35 employs this strategy using its electronic warfare suite. BAE systems, the producer of the F-35 AN/ASQ-239 electronic-warfare suite, states the following of the system, “the advanced avionics and sensors provide a real-time, 360-degree view of the battlespace, helping to maximize detection ranges and provide the pilot with options to evade, engage, counter or jam threats.”¹³ Placing the jamming aircraft closer to the threat maximizes the power output directed toward the enemy SAM system. It also reduces the overall operational risk by decreasing reliance on dedicated standoff jamming platforms. Stand-in jamming is a technology that successfully shifts the offense-defense balance towards the advantage of the attacking aircraft.

As advanced modern SAMs continue to evolve, the digital components that comprise the systems gain increasing capability. These digital components enable sophisticated electronic counter measures. The digital components of modern systems make it very easy to rapidly change the parameters of the system’s radio wave signals. Paul Tilman of DARPA explains how current US countermeasures to such systems are obsolete: “today’s EW functions are a holdover from Vietnam-era EW practices.”¹⁴ Vietnam era surface-to-air technology was made from mostly analog components. This made it exceedingly difficult for the SAM operators to change the parameters of the signals, especially in field conditions. With analog systems, the US could simply program the signals into a database and associate an offensive or defensive

¹² Haystead, John. “The Future of Airborne Electronic Attack.” *Journal of Electronic Defense* Vol. 39 Issue 12, 2016, 38.

¹³ Caruso, Todd. AN/AQ-239 Electronic Warfare/Countermeasure System Datasheet. BAE Systems, May 2016.

¹⁴ Haystead, John. “The Future of Airborne Electronic Attack,” 58.

countermeasure to each set of signals. There was very little possibility that the ground-based threat would change parameters to render the countermeasures useless. The digital components of modern SAM systems change the game. The modern digital SAM can change its parameters faster than engineers can keep a look-up table current. The air weapon requires a new method of executing electronic attack to prevent a further shift to the defensive. The next step in electronic warfare technology that addresses this shortfall is called cognitive electronic attack. John Knowles, writing in the *Journal of Electronic Defense*, explains that “cognitive EW [electronic warfare] is one step beyond this [adaptive EA], where the EW system not only adapts based on what it observes but it also uses Artificial Intelligence (machine learning) to actually learn what EW technique is working best at any given time and remembers that so the next time it encounters those threat characteristics again [sic] it goes immediately to that technique.”¹⁵ Cognitive electronic attack allows the offensive air platform to react in real time to new systems on the battlefield as well as changing characteristics of known systems. No longer will a modern SAM be able to simply switch a parameter to defeat an electronic attack. Advanced electronic attack shifts the advantage toward the offender.

Decoys

Decoys attempt to further restore air power’s offensive advantage by capitalizing on the time-tested principles of mass and deception. The main tool the United States uses to leverage the principle of deception is the Miniature Air Launched Decoy (MALD). Raytheon, the creator of MALD, describes the vehicle as “an expendable air-launched flight vehicle that looks like a U.S. or allied aircraft to enemy integrated air defense systems (IADS).”¹⁶ John Haystead, in the *Journal of Electronic Defense*, describes the utility of the vehicle when he says “built by Raytheon Missile Systems Division (Tucson, AZ), and with a range of approximately 500 nmi, the baseline MALD platform is an air-launchable, low-cost, modular flight vehicle that emulates the radar signatures and

¹⁵ Knowles, John. “Regaining the Advantage – Cognitive Electronic Warfare.” *Journal of Electronic Defense* Vol. 39 Issue 12, 2016, 38.

¹⁶ Raytheon. “Miniature Air Launched Decoy.” Raytheon.com. <http://www.raytheon.com/capabilities/products/mald/> (accessed March 3, 2017).

combat flight profiles of US and allied aircraft.”¹⁷ The decoys are intended to fly into high-risk areas to confuse enemy IADS as to the true location of an offensive operation. Other uses of MALD include the ability to fly into a defended area ahead of manned platforms forcing an IADS response and thereby revealing previously unknown enemy SAM locations. Decoys can trigger alert launches from enemy interceptor airfields allowing offensive forces to time their attacks as the enemy interceptors run out of fuel and/or weapons. If there are enough decoys available, they can be used to simply run the enemy SAM systems out of missiles before the main strike package arrives.

A second version of MALD, the MALD-J, aims to further deceive enemy IADS by incorporating stand-in jamming. Raytheon missile systems explains, “MALD-J is the jammer variant of the basic decoy, and the first ever stand-in jammer to enter production. The unmanned MALD-J navigates and operates much closer than conventional EW [electronic warfare] to the victim radar when jamming the electronics, allowing aviators and aircraft to stay out of harm’s way.”¹⁸ The MALD-J attempts to deceive enemy IADS by hiding the manned strike package from the radar components of the system. The MALD-J seeks to break the kill chain by jamming enemy radars, denying them the capability to target manned platforms. The concept was proven in a 2011 operational test. John Haystead explains, “in a test involving a combination of captive-carry and free-flying miniature air launched decoy jammers (MALD-Js), flying within a simulated operational environment, the USAF demonstrated that the system could protect a full strike package of manned aircraft.”¹⁹ Combining MALD and MALD-J attempts to reinforce an offensive airpower advantage by capitalizing on the principles of mass and deception.

Swarm Technology

Swarming of unmanned aerial vehicles is the final technology that potentially advantages the offender in a modern SEAD environment. Paul Scharre describes the

¹⁷ Haystead, John. “MALD-J Successfully Demonstrates Manned Aircraft Protection Capability.” *Journal of Electronic Defense* Vol. 34 Issue 10, 2011, 15.

¹⁸ Raytheon. “Miniature Air Launched Decoy.” Raytheon.com. <http://www.raytheon.com/capabilities/products/mald/> (accessed March 3, 2017).

¹⁹ Haystead, John. “MALD-J Successfully Demonstrates Manned Aircraft Protection Capability.” *Journal of Electronic Defense* Vol. 34 Issue 10, 2011, 15.

basic concept of a swarm when he says, “low-cost uninhabited systems can be built in large numbers, “flooding the zone” and overwhelming enemy defenses by their sheer numbers.”²⁰ Scharre goes on to report that large numbers of cheap drones offer four potential advantages. The first is that drones offer the ability to disperse combat power, making the enemy dedicate significant resources to target the isolated drones. Second, swarms of drones are inherently resilient. Any drone that is shot down is simply replaced by another low-cost vehicle. Third, swarms offer graceful degradation in capability. If one is shot down, there is no “sharp loss in combat power.”²¹ The fourth advantage provided by swarms is that they, by their very nature, saturate enemy defenses. By saturating defenses with relatively inexpensive drones, one can impose a significant cost on the enemy. Scharre calls this strategy “bending the cost curve.” He illuminates the concept through the following graph:

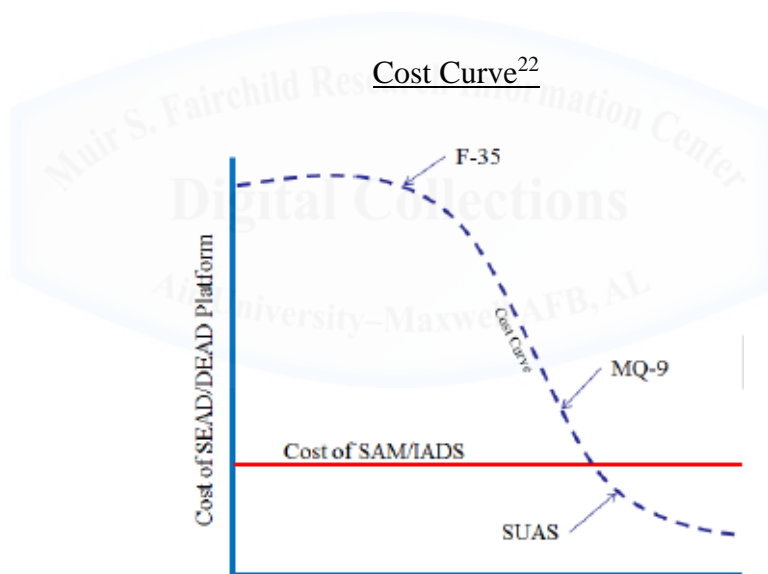


Figure 1. Bending the Cost Curve

Source: Paul Scharre, “Robotics on the Battlefield Part II: The Coming Swarm.” Center for a New American Security, October 2014, 54.

²⁰Paul Scharre, “Robotics on the Battlefield Part II: The Coming Swarm.” Center for a New American Security, October 2014, 10.

²¹ Paul Scharre, “Robotics on the Battlefield Part II: The Coming Swarm.” Center for a New American Security, October 2014, 14.

²² Small Unmanned Aircraft Systems (SUAS)

By relying on Small Unmanned Aircraft Systems (SUAS) that cost much less than a SAM, one can impose unsustainable costs on an adversary, successfully tipping the balance toward the offender.

This chapter shows that advances in technology continue to impact relationships of offense to defense in airpower. Modern stealth seeks to maintain the offensive advantage of airpower by defeating IADS at critical points in the kill chain. The rapidly increasing capabilities and maximum effective ranges of modern advanced surface-to-air missile systems seek to remove any of the advantages achieved by low observable aircraft. Modern electronic attack, airborne decoys, and swarming technology achieve incremental increases in the offensive prowess of airpower but remain untested in open combat against a peer adversary. Nonetheless, the offensive side of airpower continues to hold advantage.



Chapter 5

Tying Together Theory, History, the Present, and the Future of Offense/Defense in Air Warfare

We must look toward the future with anxious, wide-open eyes to steel ourselves for what may come, so that the reality may not take us by surprise.

Giulio Douhet

Douhet's theories on the offensive utility of airpower prove enduring even in the face of technological advances specifically designed to limit airpower's utility. He argues that "there is only one valid way to defend oneself from aerial offensives; namely, *to conquer the command of the air*, that is to *prevent the enemy from flying, while assuring this freedom for oneself*."¹ Douhet argues that no amount of technological innovation can significantly degrade the offensive advantages of the air weapon. If a technology attempts to remove air power as an offensive tool altogether, Douhet's proposition rings especially true. He argues that even if the air weapon itself cannot decisively win a war, it will pave the way for traditional naval and ground forces to triumph. Speed and the ability to step over terrain and defensive structures endow airpower with an offensive advantage that can only be degraded, not completely taken away. Adding to this advantage is air power's ability to mass in both numbers and precision on nearly any target the offender chooses. These innate abilities present a situation where the defense against the air weapon becomes untenable. The air arm required to defend a country against air attack often will exceed the industrial and monetary capabilities of the defending nation state.

Clausewitz argued that the defensive is the stronger form of warfare but also acknowledged the cat-and-mouse game between the offensive and defensive camps. He states, "if the offensive were to invent some major new expedient—which is unlikely in view of the simplicity inherent necessity that marks everything today—the defensive will also have to change its methods."² The air weapon qualifies as a type of major new

¹ Giulio Douhet, *The Command of the Air*, USAF Warrior Studies, Washington, D.C: Office of Air Force History, 1983, 191.

² Carl von Clausewitz, Michael Eliot Howard, and Peter Paret, *On War*, First paperback printing (Princeton, NJ: Princeton University Press, 1989, 362.

expedient that Clausewitz mentions above. Just as he posits, states wishing to limit the offensive utility of airpower look for technological solutions to change the methods of defense. Douhet's theory proves enduring. A brief review of the technologies highlights the link between the theory and the history of technologies that attempt, unsuccessfully, to erase the utility of the air weapon.

The first technology that illuminates the link between Douhet's theories and the history of airpower in war is radar. As evidenced in the analysis in chapter two of this work, radar indeed proves to limit the offensive utility of airpower. Early-warning networks that combine radar with visual observers, searchlights, and acoustic receivers allow defensive forces to remain on the ground instead of airborne executing combat air patrols. This enables the defenders to launch in response to offensive raids and capitalizes on the ability to mass against the attackers. This strategy was effective for the English during the Battle of Britain. Radar also provides anti-aircraft artillery and surface-to-air missile systems accurate cueing with which they can organize increasingly lethal defenses. Radar proves to limit but not eliminate air power's offensive nature.

In response to the offense-limiting capabilities presented by radar, both Germany and the Allies turned to technology to tip the balance in favor of the attack. Electronic attack became an avenue with which both sides could limit the dangers posed by enemy radar networks. The technology presents a double-edged sword to strategists depending upon how both the offender and the defender utilize the innovation. Offensive uses of electronic attack enable air forces to blind early-warning radars, restoring the element of surprise, and an advantage to the offensive. The technology can also render firing solutions critical to anti-aircraft artillery and surface-to-air missile systems useless, another offensive advantage. On the defensive, spoiled navigation-and-bombing solutions hide the true location of targets, degrading the effectiveness of attacks. When used offensively, electronic attack proves to be a valid tool to limit the effect radar has on stripping airpower of its offensive nature. Combined with additional offense-enabling technologies, such as Window, electronic attack proves to promote the offensive utility of the air weapon.

Window, the precursor to modern day chaff, is a technological development that complements other innovations designed to maintain the offensive nature of air power.

As evidenced during the Normandy landings, airpower, combined with Window and electronic attack, enabled offensive actions both on the ground and in the air. Window, combined with offensive electronic attack proves to maintain air power's offensive advantages when facing a radar-equipped adversary. One can begin to see what is required for airpower to maintain its offensive utility when faced with increasingly advanced defensive technologies. Complementary offensive technologies create effects that degrade the utility of defensive systems. By combining mass with electronic attack and Window technology, the Allies were able to execute successful offensive air operations over occupied Europe. A similar approach, one of complimentary offensive capabilities, is required to maintain air power's advantages in both the present and the future.

Flak is an enduring form of technology that successfully degrades the offensive utility of air power. Flak drives attacking aircraft to higher altitudes which, prior to the advent of precision weapons, reduces the accuracy of weapons. Flak demands that aircraft fly evasive maneuvers, breaking up formations and further reducing both the accuracy and number of bombs successfully employed on targets. Although flak is still in use today, it serves only to degrade the offensive utility of airpower. Douhet's theories help to explain why flak does not provide a decisive advantage for the defender. The quantity of anti-aircraft artillery pieces required to mount an effective defense limits the utility of flak. This concept is strikingly similar to Douhet's theory on the difficulties of aerial defense. Douhet's theory leads to the conclusion that the money spent on the large numbers of artillery pieces required to effectively defend all of a state's vital centers is better spent on offensive platforms. Flak proves to degrade the offensive but the nod still goes to airpower.

The next technology that threatened to challenge airpower as an offensive tool is the surface-to-air guided missile. The injection of the technology into the Vietnam conflict caused similar consequences as the introduction of flak into World War II. The surface-to-air missile put both bombers and fighters at risk, forcing them to fly alternate flight profiles. Fighters were forced into the low-altitude environment to avoid the SA-2, which put them back into the heart of the envelope for flak engagements. Bombers were forced to take evasive action in response to missile launches degrading the effectiveness

of their attacks. The surface-to-air missile comes dangerously close to invalidating portions of Douhet's theories on the difficulties of the defense. In theory, well-placed missile systems could indeed defend large swaths of airspace over a state's vital centers. The systems are relatively inexpensive when compared to the requirements of mounting an equivalent defense with airplanes. The advent of the surface-to-air missile threatened the offensive primacy of airpower but did not decisively shift the balance. The meager capabilities of early missile technology combined with increases in technological innovation on the offensive side limited the impact of the technology. Breakthroughs in radar-homing-and-warning systems, electronic attack, and anti-radiation missiles combine to reduce the danger of the surface-to-air missile to the offensive advantages of airpower.

Radar-homing-and-warning systems gave aircrews in Vietnam a method for detecting the radio-frequency emissions from surface-to-air missile systems before and after missile launch. The systems provided the crews advanced warning and a general location of radio-frequency threats. Before the technology existed, crews were forced to either visually detect the missile launches or rely on voice warnings from specialized electronic-support aircraft. The radar-homing-and-warning systems allowed for early detection and optimized threat reactions against the lethal surface-to-air missiles. The radar-homing-and-warning equipment represents one of the small technological innovations that work to restore airpower's offensive utility, when combined with complementary technologies. The combination of the radar-homing-and-warning equipment with electronic warfare pods mounted on fighter aircraft work to maintain air power's offensive prowess, just as Douhet argued.

Much like radar-homing-and-warning systems, electronic-warfare pods merged with other technologies to maintain the offensive advantage of airpower. By placing podded electronic-warfare equipment on fighter-bombers, the United States optimized the electronic attack for the specific platform being targeted. The radar-homing-and-warning systems gave the pilots the information required to optimize their defensive maneuvers, while the podded electronic-warfare equipment worked to spoil missile shots electronically. Combining the individualized electronic-warfare technology from the pods with the radar-homing-and-warning systems provided an effective defense for

individual aircraft. Adding one more technology, an offensive weapon designed to kill surface-to-air missiles, maintained air power's primacy in the face of increasingly capable defensive systems.

Anti-radiation missiles, combined with radar-homing-and-warning equipment and electronic warfare pods, create a combination that reinforces airpower's offensive utility consistent with Douhet's theories. The anti-radiation missile gave aircrews a method to suppress and destroy the critical radar components of surface-to-air missile systems. The offensive missiles allowed for self-defense of the fighter-bombers as well as the collective defense of strike packages. The weapon was so successful that the mere presence of the Wild Weasel aircraft would deter radar operators from activating their equipment resulting in far fewer threat reactions. With fewer threat reactions from the surface-to-air missiles, aircrew were able to concentrate on accurately releasing their weapons.

When a groundbreaking technology such as the radar-guided surface-to-air missile debuts in a conflict, it starts a race to find countermeasures. As the defensive technologies become more sophisticated, they also become more capable. The above discussion highlights a nuanced shift in how the offense-defense balance changes in the modern era. As a defensive capability is fielded, there is a period of adjustment on the offensive side. This period of adjustment takes a path that results in multiple innovative technologies coming together to create combined effects. The combination of radar-homing-and-warning equipment, electronic attack, and the anti-radiation missile was required to restore the offensive utility of airpower in the face of surface-to-air missile technology. A similar line of development is apparent with the advent of integrated air defense systems and the stealth and precision weapon technology required to defeat them.

Integrated-air-defense systems, such as the one encountered by coalition aircraft over Iraq in 1991, attempt to optimize the actions of a vast network of defenses. The system seeks to remove the offensive advantages gained through the combined technologies that proved so successful during the Vietnam conflict. The integrated-air-defense system seeks to remove the difficulties in defending large amounts of territory, thus rendering Douhet's theories incorrect. By optimizing each component of a defensive system and integrating it into a central command-and-control network, the

defending state can organize effective countermeasures with a minimal number of expensive missile and artillery pieces. The integrated-air-defense system tends to favor the defense but once again does not completely remove the offensive utility of airpower when technologies combine to create complementary effects.

A technological development on par with the groundbreaking introduction of the integrated-air-defense system and the surface-to-air guided missile is stealth technology. The technology is specifically designed to defeat an integrated-air-defense system, thus privileging the offense. Stealth technology was put in action with dramatic results over Iraq thanks to the F-117. The Iraqi early-warning radars were unable to detect the oddly shaped aircraft. With no detections from the early-warning radars, the command-and-control elements of the Iraqi system had no knowledge of the stealthy fighters as they approached their targets. Surface-to-air missiles as well as the anti-aircraft artillery never received warning of the impending attacks until the bombs began destroying their targets. Although groundbreaking on its own, stealth technology had to be paired with other technological advances to be successful against integrated-air-defense systems. Stealth technology combined with precision weapons served to favor the offensive when facing an integrated air defense system.

Stealth technology capitalizes on the element of surprise in order to defeat an integrated-air-defense system. As soon as the first bomb goes off, the element of surprise is degraded. An anti-aircraft gun with a simple spotlight has the capability to destroy an F-117. This paradox creates a requirement to destroy critical targets with precision on the first try. Precision weapons are the technology that pairs with stealth advancements to maintain the offensive utility of the air weapon when faced with an integrated-air-defense system. With precision weapons, a single flight of F-117s can reliably destroy the targets that would take an entire strike package to annihilate. The F-117 over Iraq needed little-to-no outside support. The same is not true for the non-stealthy fighters and bombers of the time. Combining stealth with precision weapons, the airplane maintains its offensive advantage.

Moving on to the present state of technology, the same conclusions can be drawn about the importance of combining multiple offensive technologies to defeat increasingly capable defensive innovations. The modern advanced surface-to-air missile system

provides a significant increase in both capability and range over its predecessor. The long range of the modern SAM has become the most significant challenger to Douhet's theories on the offensive utility of airpower. With only a few relatively inexpensive modern SAMs, a nation state can effectively mount a defense over large portions of its territory. The modern SAM empowers the defense more than any other technology discussed to this point. Fortunately, the United States has not been forced to confront a state equipped with a modern SAM network. The lack of great-power war allows time to explore offensive technologies that, when combined, will maintain air power's offensive prowess.

Modern stealth, beyond that built into the F-117, is the first innovation that combines with advanced electronic attack, decoys, and swarm technology to maintain the offensive advantage of airpower. Modern stealth allows the platform designers to optimize their aircraft for defeating specific threat radars. The tailored platforms afford strategists a menu of assets from which to optimize attacks against the specific threat. If a planner wants to break the kill chain at the early warning stage, he may employ a B-2 or B-21. If the strategist desires to break the kill chain at the engagement stage he may employ an F-22 or F-35. The tailorable nature of modern stealth allows strategists to create the conditions for success in an air operation. Combining modern stealth with advanced electronic attack further increases the likelihood that air offensives will hold up in future conflicts. Equipping stealth strike platforms such as the F-35 with both precision weapons and electronic-attack equipment provides complementary effects. The stealth delays the range at which an enemy defender can detect the platform while electronic attack masks the platform's true location. Combine these two symbiotic effects with off-board support, and offensive airpower maintains the advantage. Decoy technology, such as the ADM-160 Miniature Air Launched Decoy (MALD), is an example of this type of support technology that enables offensive air operations when facing increasingly capable defenses. Decoys seek to confuse the command-and-control elements of an enemy's defensive systems. The decoys, combined with electronic attack, create mass confusion in an integrated-air-defense system, severely degrading the effectiveness of any countermeasures. Even if the defenders can sort through the fog and friction that jamming causes, they are then forced to decipher decoys from stealth

aircraft. Combining swarming technology with these effects further exacerbates the defender's problem. A swarm of small air vehicles that appear threatening to the enemy defensive system imparts a cost on the enemy in the form of relatively expensive missile bodies. If a defender is forced into the situation where he must shoot everything down because he cannot decipher the true threats from the swarms of decoys, he will quickly run out of ammunition. In addition, as the systems waste their missiles on the swarms of low-cost, unmanned aircraft, their locations are made apparent, exposing the systems to potential attacks.

The future of the offensive air weapon follows from the theories of Giulio Douhet and inherent capabilities. There will be seemingly insurmountable defensive obstacles as technological advances appear. For a time, the nod will go to the defensive but this advantage will be fleeting. The offensive regains the advantage through the combination of multiple technological advances that combine to defeat emerging defensive systems. A common misconception occurs when faced with a seemingly paradigm-shifting new defensive development. The history of this phenomenon suggests that there may always be an offensive counter. The sky is big, relative to air maneuverability the defense is stationary, and aircraft are mobile. These things will not change

Bibliography

- Bungay, Stephen. *The most dangerous enemy: a history of the Battle of Britain*. Aurum Press Limited, 2010.
- Carl von Clausewitz, Michael Eliot Howard, and Peter Paret, *On War*, First paperback printing (Princeton, NJ: Princeton University Press, 1989.
- Caruso, Todd. AN/AQ-239 Electronic Warfare/Countermeasure System Datasheet. BAE Systems, May 2016.
- Clark, Ronald William. *The Rise of the Boffins*. Phoenix House, 1962.
- Cohen, Eliot A. *Gulf War Air Power Survey*. US Government Printing Office, Washington DC, 1993.
- Davis, Larry. *Wild Weasel: the SAM suppression story*. Squadron/Signal Publications, 1993.
- Giulio Douhet, *The Command of the Air*, USAF Warrior Studies, Washington, D.C: Office of Air Force History, 1983.
- Hampton, Dan. *The Hunter Killers: The Extraordinary Story of the First Wild Weasels, the Band of Maverick Aviators Who Flew the Most Dangerous Missions of the Vietnam War*. New York, NY: William Morrow, 2015.
- Hannah, Craig C. *Striving for Air Superiority: The Tactical Air Command in Vietnam*. Texas A&M University Press, 2002.
- Haystead, John. "MALD-J Successfully Demonstrates Manned Aircraft Protection Capability." *Journal of Electronic Defense* Vol. 34 Issue 10, 2011.
- Haystead, John. "The Future of Airborne Electronic Attack." *Journal of Electronic Defense* Vol. 39 Issue 12, 2016.
- Hopf, Ted. "Polarity, The Offense Defense Balance, and War." *The American Political Science Review* 85, no. 2, 1991, 476.
- Jones, Reginald Victor. *Most Secret War*. Penguin UK, 2009.
- Knott, Eugene F., Shaeffer, John F., Tuley, Michael T., "Radar Cross Section." Second Edition, SciTech Publishing, 2004.
- Knowles, John. "Regaining the Advantage – Cognitive Electronic Warfare." *Journal of Electronic Defense* Vol. 39 Issue 12, 2016.

- Kopp, Carlo. Technical Report APA-TR-2009-0503, Australian airpower.net, <http://www.ausairpower.net/APA-S-400-Triumpf.html>, accessed 8 March 2017.
- Kopp, Carlo. Technical Report APA-TR-2009-0702, Australian airpower.net, <http://www.ausairpower.net/APA-S-75-Volkhov.html>, accessed 8 March 2017.
- Kuhn, Thomas S. *The Structure of Scientific Revolutions*. fourth ed. Chicago: The University of Chicago Press, 2012.
- Majumdar, Dave. "Revealed: China's Radars Can Track America's Stealthy F-22 Raptor." Nationalinterest.org. <http://nationalinterest.org/blog/the-buzz/revealed-can-chinas-radars-track-americas-stealth-f-22-15261> (accessed March 1, 2017).
- Owen, Robert C. *Deliberate Force. A Case Study in Effective Air Campaigning*. Air University Press, Maxwell AFB AL, 2000.
- Paterson, John. "Overview of low observable technology and its effects on combat aircraft survivability." *Journal of Aircraft* 36, no. 2, 1999.
- Paul Scharre, "Robotics on the Battlefield Part II: The Coming Swarm." Center for a New American Security, October 2014.
- Rankin, William. "The Geography of Radionavigation and the Politics of Intangible Artifacts." *Technology and Culture* 55, no. 3 July 2014.
- Raytheon. "Miniature Air Launched Decoy." Raytheon.com. <http://www.raytheon.com/capabilities/products/mald/> (accessed March 3, 2017).
- Warden, John A. *The Air Campaign: Planning for Combat*. iUniverse, 1998.
- Westermann, Edward B. *Flak: German Anti-aircraft Defenses, 1914-1945*. University Press of Kansas, 2001.
- Zhang, Xiaoming. *Texas A&M University Military History Series*. Vol. 80, *Red Wings Over the Yalu: China, the Soviet Union, and the Air War in Korea*. College Station: Texas A & M University Press, 2002.
- Zikidis, Konstantinos, Alexios Skondras, and Charisios Tokas. "Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies." *Journal of Computations & Modeling* 4, no. 1, 2014.